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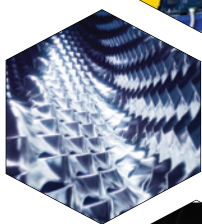

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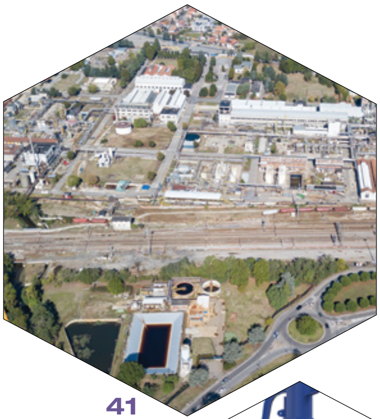

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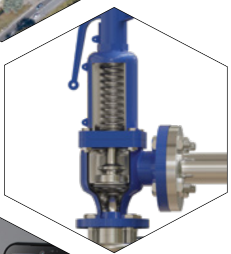

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CHEMICAL ENGINEERING
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Editor's Page

Rising heat concerns

This summer is proving to be a hot one across much of the U.S. as heat waves grip many regions with little relief from nighttime cooling. If it seems like it has been getting hotter, there are data to support that premise.

Last month, the U.S. Environmental Protection Agency (EPA) released a report describing the far-reaching impacts of climate change on people and the environment [*1*]. The report, which includes historical data and observed trends, uses 39 of 57 key indicators that the EPA follows to keep abreast of the effects of climate change. EPA partners with more than 50 data contributors from various U.S. and international government agencies, academic institutions and other organizations to compile the key indicators of climate change that it monitors. The eight chapters in the lengthy report cover various topics indicating the extensive effects of climate change including: greenhouse gases; rising temperatures; extreme events, such as heavy rainstorms, hurricanes, floods, droughts and wildfires; water resources; seasonal changes; ocean impacts; rising sea levels; and warming effects specific to Alaska.

Working in extreme heat

Worldwide, 2023 was the warmest year on record and 2014–2023 was the warmest decade on record since thermometer-based observations began, according to the EPA report. And overall, the U.S. is seeing a somewhat higher average rate of temperature rise than the global rate, as concentrations of greenhouse gases in the atmosphere increase. What were once considered "unusually" hot summer days and nights have become more common over the last few decades. Part of the concern about this trend is that extreme heat can have debilitating effects on human health.

According to the U.S. Occupational Safety and Health Administration (OSHA), heat causes more deaths in the U.S. than any other hazardous weather condition. Two of the groups of people at risk are outdoor workers, such as in construction or agriculture, and workers in indoor areas without air conditioning, such as in many manufacturing facilities and warehouses. In addition to environmental temperatures, heat-generating processes and machinery can also put workers at risk.

From 2011 to 2022, 479 workers in the U.S. were reported to have died from environmental heat exposure, and from 2011 to 2020, there were 33,890 estimated work-related heat injuries and illnesses that caused workers to miss time from work. OSHA comments that these statistics are even likely underestimated [*2*].

OSHA's proposed rule

OSHA is taking a step toward a federal heat standard to protect workers by issuing a Notice of Proposed Rulemaking for Heat Injury and Illness Prevention in Outdoor and Indoor Work Settings. With the standard, employers would be required to evaluate and create a plan to control heat hazards in the workplace. The public can submit comments about the propsed rule. More information can be found on OSHA's website [*3*]. ■

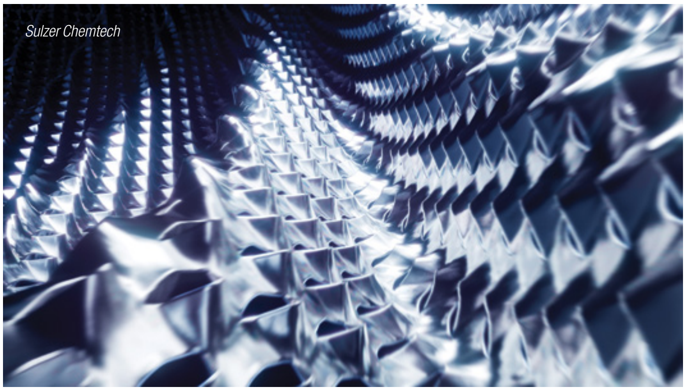
Dorothy Lozowski, Editorial Director

1.U.S. Environmental Protection Agency, Climate change indicators in the United States (Fifth ed., EPA 430-R-24-003), www.epa.gov/climate-indicators, July 2024.
2. OSHA, www.osha.gov/heat-exposure/rulemaking
3. www.osha.gov/laws-regs/rulemakingprocess#v-nav-tab2

New structured packing introduced at Achema

At Achema 2024 (Frankfurt, Germany; June 10–15), Sulzer Chemtech (Winterthur, Switzerland; www.sulzer.com) revealed MellapakEvo (photo), the latest addition to its structured-packing product family. The MellapakEvo structured packing has been developed to enhance the efficiency and capacity of distillation columns, maximizing performance while minimizing energy consumption with a lower pressure drop. The new design allows it to offer up to 40% greater efficiency compared to MellapakPlus 252.Y at similar capacity, or 20% more capacity compared to MellapakPlus 452.Y at similar efficiency, the company says. The comparisons were confirmed by an independent, international organization.

The increased performance of the MellapakEvo structured packing is a result of several innovative changes to its structure. The optimized packing geometry of MellapakEvo enhances liquid spreading and improves liquid surface renewal, which is critical to the mass transfer required in a distillation column. Greater interaction between liquid and gas phases ensures a more efficient mass transfer. Moreover, the structured packing is suitable for a wide range of distillation processes. It is said to be ideal for use in diverse applications in the chemical process industries (CPI) where its ability to offer both high efficiency and a low pressure drop is vital.


Sulzer Chemtech

Pilot plant produces climate-friendly cement clinker

Concrete production is responsible for 6–9% of global anthropogenic CO_2 emissions. "The largest contribution to that comes from the production of cement, a precursor product," says Peter Stemmermann from the Institute for Technical Chemistry (ITC) at the Karlsruhe Institute of Technology (KIT; www.kit.edu). "An important component of typical Portland cement is clinker, which is produced in an energy-intensive process by heating limestone." Stemmermann's research group has developed a clinker that is made instead from recycled concrete and only partly from limestone.

To produce belite cement clinker, the pilot plant uses an all-electric heating system powered by renewable energy and a carbon dioxide atmosphere, reducing the energy required for the process. "We can manage with a process temperature of 1,000°C instead of 1,400°C in the rotary kiln," Stemmermann says. Compared with conventional clinker production, the overall energy consumption is 40% lower. "The CO_2 unavoidably emitted as a result of the limestone reaction in the kiln is captured and then bound to the recycled concrete in the second step of the process," Stemmermann explains. This second step is to be integrated in a future expansion of the pilot plant, which is currently capable of producing 100 kg/d of clinker.

Circular concrete from KIT's plant is climate-neutral thanks to the direct link between the production of clinker and the production of carbonated aggregate (the coarse fill material in concrete). The CO_2 from clinker production is used directly in the carbonation hardening of coarse-grained concrete waste, where it is permanently bound. The heat generated during clinker production is also used in this step, which takes place in an autoclave, making it particularly energy-efficient. "The result is a high-quality aggregate," Stemmermann says. "We were able to prove beyond doubt that carbonation improves the microstructure of the aggregate by reducing its porosity." The resulting aggregate is then processed with belite cement to produce circular concrete with a balanced overall carbon footprint.

Edited by:
Gerald Ondrey

TANNING AGENT

Södra Skogsägarna (Södra; Växjö, Sweden; www.sodra.com) is investing in a production line at Värö that will create a tanning agent from tree bark. This new tannin can be used to process leather in a more environmentally friendly way, the company says. Scheduled to be commissioned in 2026, the plant will have the capacity to produce tannins for millions of square meters of leather.

Since 2006, Södra Innovation, a business area within the member-owned forest group, Södra, has been exploring how tannins found in the bark of trees can be efficiently processed and used as tanning agents. Using bark for tanning is not new, but Södra is now industrializing the process in which the tanning substance is leached from the bark and turned into a product for tanning leather. "With this new patented process, we can now make a product from an, until now, unused resource," says Catrin Gustavsson, business area manager at Södra Innovation.

BIO-BASED FUMARATE

With the bacterium *Basfia succiniciproducens*, BASF SE (Ludwigshafen, Germany; www.basf.com) intends to transform sugar and carbon dioxide into fumaric acid, an important intermediate for chemical production. To this end, the company is collaborating with Saarland University, University of Marburg and the University of Kaiserslautern-Landau in a joint research project entitled FUMBIO (FUMarsäure BIObasiert).

The bacterium, which was isolated in 2008 from the rumen of a Holstein cow, will be genetically modified by researchers so that it produces large quantities of bio-based fumaric acid (fumarate) during fermentation. With this intermediate, BASF can make a wide range of products with a low carbon footprint, including additives for food and animal feed, starting materials for medication, or building blocks for polymers and detergents and formulators. The research project also focuses on the subsequent refinement of fumarate by enzymes into biodegradable industrial products.

(Continues on p. 6)

The FUMBIO project received €2.6 million in financial support from Germany's Federal Ministry for Education and Research.

IMMERSION COOLING

Perstorp Holding AB (Malmö Perstorp, Sweden; www.perstorp.com) and Intel Corp.'s (Santa Clara, Calif.; www.intel.com) Open IP Advanced Liquid Cooling team have developed a high-performance synthetic thermal-management fluid specifically designed for immersion cooling in data centers.

The partners recently participated in Computex 2024 in Taipei, where Intel showcased its Gaudi 3 AI accelerator technology. The accelerator uses Intel's SuperFluid Cooling Technology, which leverages the low viscosity and high flash point balance of Perstorp's advanced synthetic thermal-management fluid.

In comparison to conventional, single-phase immersion cooling with its cooling capacity of about 500 W per chip, Intel's SuperFluid technology, which uses air as a lubrication system, can increase cooling capacity to 800 W. The cooling capacity per chip can be further improved to 1,500 W when this is combined with the low-viscosity properties of Perstorp's advanced synthetic thermal-management fluid, together with flow-field management, optimized system control and intelligent management of the Cooling Distribution Unit.

SOLAR FUELS

Last June, Synhelion S.A. (Lugano, Switzerland; www.synhelion.com) inaugurated DAWN, the world's first industrial-scale plant to produce synthetic fuels using solar thermal energy. Located in Jülich, Germany, DAWN features a 20-m-high solar tower that contains a solar receiver, a thermochemical reactor and a thermal-energy stor-

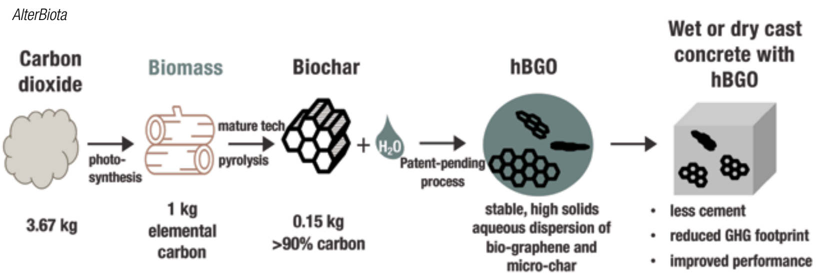
(Continues on p. 8)

New bio-based concrete admixture is scaling up production

A new biomass-based liquid admixture for concrete uniquely combines the benefits of traditional performance-enhancing additives with decarbonization. Hydrous bio-graphene oxide (hBGO), developed by AlterBiota (Edwardsville, Nova Scotia, Canada; www.alterbiota.com), is a stable, high-solids dispersion that helps to improve strength and durability, reducing the amount of carbon-intensive and expensive Portland cement used, while also drastically reducing the carbon footprint via the use of carbon-negative feedstock. Unlike other lower-carbon concrete technologies like carbonation or supplemental cementitious materials, hBGO requires no modification to admixture dosing systems or batching practices. And other performance-enhancing additives, such as superplasiticizers, are significantly more carbon-intensive than hBGO, as they are derived from fossil-fuel feedstocks.

"Greater than 80% of our admixture is derived from biomass carbon. hBGO is produced by pyrolyzing lignocellulosic biomass from the forestry industry using standard indirectly fired rotary-kiln technology to create a highly graphitic biochar precursor for our patent-pending high-shear liquid-phase milling and exfoliation process," explains Mark Masotti, CEO of AlterBiota. This one-pot, water-based process requires no downstream separation or effluents and only uses standard process equipment. "We have demonstrated pilot production at the scale of 250 L per batch, which is convenient for commercial trials using standard 208-L industrial drums," adds Masotti.

The company recently moved its operations into a 3,000-ft^2 plant outside Sydney, Nova Scotia, and is currently working with piloting partners on industrial trials with plans to expand these activities throughout the coming months. The company was recently awarded CAN$4 million in seed financing to further develop and commercialize its sustainable concrete additive.



AlterBiota

A biocatalytic process for producing nitriles — without cyanide

Nitrile compounds (R–N≡N) are important for the manufacturing of fragrances, pharmaceuticals, superglue and chemical-resistant gloves. Currently, such nitrile compounds require the use of highly toxic cyanide in their synthesis. Now, an alternative cyanide-free chemo-enzymatic cascade process is being developed by a research team from Graz University of Technology (TU Graz; Austria; www.tugraz.at) and the Czech Academy of Sciences (Prague; www.avcr.cz) in a project funded by the Austrian Science Fund FWF and the Czech Science Foundation (GACR).

The project, led by Margit Winkler from the Institute of Molecular Biotechnology at TU Graz and Ludmila Martínková from the Institute of Microbiology at the Czech Academy of Sciences, revolves around a biocatalytic process that does not require cyanide, works at room temperature and therefore requires less energy and produces less harmful waste. To replace the cyanide, the research group uses enzymes and combines three individual reactions into a cascade. In the first step, a carboxylic acid (such as fatty acids from plant oils or lignin, a byproduct of wood processing) is converted to an aldehyde by adding sugar, oxygen and the enzyme carboxylate reductase contained in living bacterial cells. This highly reactive, unstable aldehyde is reacted with hydroxylamine to make a stable oxime. In the final step, the enzyme aldoxime dehydratase is used to remove water from the oxime to give the desired nitrile.

So far, the method has only produced small quantities of nitriles — which may be sufficient for potent fragrances, but has not been optimized for scaling up to larger amounts. Winkler is currently conducting research on how to make the first step more efficient. Dehydration of the oxime alone, on the other hand, is extremely efficient and already reached technical maturity for production today.

age that enables cost-efficient solar fuel production around the clock. A field of mirrors (heliostats) focus sunlight onto the receiver to supply the energy for the process.

On-site, the DAWN plant will produce synthetic crude oil, an intermediate product that is suitable to be transported. The syncrude is then processed into certified fuels in a conventional petroleum refinery. Thus, Synhelion will produce not only solar kerosene for aviation, but also solar gasoline and solar diesel.

In 2025, Synhelion will begin building its first commercial plant in Spain. The plant will produce a total of around 1,000 ton/yr of fuel.

HEAT BATTERY

Covestro AG (Leverkusen, Germany; Covestro.com) is partnering with Rondo Energy, Inc. (Oakland, Calif.; rondo.com) to install a Rondo Heat Battery at Covestro's Brunsbüttel, Germany site. The battery stores intermittent renewable electricity and delivers continuous high-temperature steam, thus offers a sustainable alternative to steam generation with fossil fuels (see *Chem. Eng.*, March 2022, p. 5).

The Breakthrough Energy Catalyst foundation set up by Bill Gates and the European Investment Bank are supporting this installation of the heat battery, which is scheduled to begin operation at the end of 2026. The project will then produce 10% of the steam required at the site, cutting CO_2 emissions by up to 13,000 ton/yr.

SIMULATING MOFS

Metal-organic frameworks (MOFs) have extraordinary properties due to their unique structure in the form of microporous crystals, which have a very large surface area despite their small size. This makes them extremely interesting for research and practical applications, such as gas storage, heat conduction and CO_2 sequestration, for example. However, MOFs are very complex systems that have so far required a great deal of time and computing power to simulate accurately. Now, a team led by Egbert Zojer from the Institute of Solid State Physics at Graz University of Technology (TU Graz; Austria; www.tugraz.at) has significantly improved these simulations using machine learning, which greatly accelerates the development and application of novel MOFs. The researchers published their method in the *Nature* journal, *npj Computational Materials*. ❒

Cyanobacteria mineralize CO_2 into biogenic construction materials

Researchers from the Fraunhofer Institute for Ceramic Technologies and Systems (IKTS; www.ikts.fraunhofer.de) and the Fraunhofer Institute for Electron Beam and Plasma Technology (FEP; both Dresden, Germany; www.fep.fraunhofer.de) are introducing an eco-friendly, biologically induced method of producing biogenic construction materials as part of the BioCarboBeton project. The process does not emit any carbon; instead, it binds CO_2 inside the material.

The centerpiece of the new method are cyanobacteria (blue-green algae) — bacterial cultures that are capable of photosynthesis. As light, moisture and temperature interact, they form limestone structures known as stromatolites. These rock-like biogenic structures have existed in nature for 3.5-billion years, which attests to the resilience and durability of this material. As part of the mineralization process, CO_2 is captured from the atmosphere and then bound in the biogenic rock.

The Fraunhofer researchers have succeeded in mimicking this natural process, by first cultivating the cyanobacteria, then adding a calcium source (such as $CaCl_2$), CO_2 and sand to enable mineralization into stromatolite-like structures. The bacterial mixture can be shaped in molds, or through spraying, foaming, extrusion or additive manufacturing into a form in which the final stages of mineralization take place. Alternatively, porous substrates can also be produced and subsequently treated with the cyanobacteria culture. The bio-based construction materials made from cyanobacteria (photo) do not contain any toxic substances.

Targeted selection of fillers and management of process and mineralization parameters allow for manufacturing of products for a wide range of different application scenarios. Potential applications include insulation material, brick, formwork filling and even mortar or stucco that cures or hardens after it is applied.

The researchers are working to scale the volumes and determine the desired solid properties. The goal is to enable manufacturers to produce the eco-friendly bio-based construction materials in the necessary volumes, quickly and cost-effectively.

Fraunhofer IKTS

Electrocatalytic reduction of CO_2 into a range of chemicals

Also at Achema in June, GIG Karasek GmbH (Gloggnitz, Austria; www.gigkarasek.com) introduced the ECO2Cell, an electrochemical CO_2-recycling technology that utilizes proprietary catalysts to convert captured carbon dioxide into a range of chemicals. Using only water, CO_2 and electricity as process inputs, the unit can be tuned to make both single-carbon products, such as carbon monoxide, formic acid and methanol, as well as multi-carbon products like ethanol and acetic acid.

The technology works by drawing CO_2 and water into an electrochemical cell and applying electrical voltage. Reduction of CO_2 occurs at the cathode, while water oxidation generates oxygen at the anode.

The chemicals produced from CO_2 depend on the manipulation of the reaction conditions and the level of voltage applied. "Product selection can be controlled by the choice of catalyst, the electrode materials, current density and electrolyte composition," explains Andreas Schnitzhofer, managing director of GIG Karasek.

The company has developed proprietary catalysts for the ECO2Cell along with a partner. Catalyst material is coated onto the electrodes within the electrochemical cell, which has three compartments, allowing the unit to generate multiple products simultaneously.

The laboratory-scale unit can convert up to 300 L/h of high-purity CO_2 into CO, with pure H_2 and O_2 as byproducts. GIG Karasek is working on scaling up the ECO2Cell to industrially relevant sizes.

Versatile production of biopolymers in new semi-crystalline format

Bio-based polymers, such as polyhydroxyalkanoate (PHA), are seeing increasing application as a more sustainable alternative to fossil-based materials. A new, flexible production platform developed by CJ Biomaterials, Inc. (Woburn, Mass.; www.cjbiomaterials.com) is now enabling the production of PHA in both amorphous (aPHA) and semi-crystalline (scPHA) formats, which enables PHA adoption in a wider range of market sectors. "Semi-crystalline PHA offers several benefits over other forms of PHA and competitive products, including better thermostability. Additionally, we have food-contact approval for both scPHA and aPHA products, expanding their potential applications in the food industry," explains Max Senechal, CJ Biomaterials' chief commercial officer.

CJ Biomaterials developed a specialized aerobic fermentation process to convert natural sugars into scPHA and aPHA. The process can precisely control the production of the co-monomers 3-hydroxybutyrate (3HB) and 4-hydroxybutyrate (4HB). By modifying these ratios, the performance properties can vary from rigid crystalline performance to very flexible with rubber-like qualities. The new process is currently running at a plant in Pasuruan, Indonesia, with a production capacity of 15,000 metric tons per year (m.t./yr). According to the company, its fermentation process enables up to 85% PHA content in microorganisms via engineered microbial strains.

"We can produce crystalline, semi-crystalline and amorphous PHAs by modifying the P3HB and P4HB ratios of our materials. An incredibly broad range of PHA polymers is made possible by this co-monomer ratio control," says Senechal. CJ Biomaterials' aPHA and scPHA are included on the U.S. Food and Drug Administration (FDA) Inventory of Effective Food Contact Substances (FCS), meaning that both can be used to manufacture food-contacting packaging materials, including rigid and flexible packaging, straws, cups and other products.

A proof-of-concept 'BionicHydrogenBattery'

At a press conference during Achema 2024, Festo SE & Co. KG (Esslingen, Germany; www.festo.com) presented the BionicHydrogenBattery — a new concept for the simple storage and safe transportation of hydrogen.

Currently, H_2 can only be stored and transported safely and in a space-saving manner using processes that require extremely high or low temperatures, and high pressures of 150–700 bars, which requires a lot of energy, said Nina Gaissert from Festo's Corporate Portfolio Projects. In contrast, the fully automated biotechnological system, the BionicHydrogenBattery, is a completely new approach, whereby H_2 and CO_2 are converted into formic acid with the help of bacteria in a low-risk and energy-efficient manner — and at comparatively low temperature (around 65°C) and a low pressure of 1.5 bars. The acid can be easily stored and transported. At the destination, the same bacteria reverse the process and decompose the acid back into CO_2 and H_2. While the latter can be used to generate electricity, the high-purity CO_2 could be recycled and used in the beverage industry, for example.

The core of the biological process is the bacterium *Thermoanaerobacter kivui*. These bacteria have a special enzyme that enables them to convert hydrogen and CO_2 into formic acid. This process was discovered and fundamentally researched by the team led by professor Volker Müller, head of the Molecular Microbiology and Bioenergetics department at Goethe University Frankfurt (Germany; www.goethe-university-frankfurt.de), with whom the Festo team is working closely on the project.

Biomimetic membrane may have promising applications

Researchers from the Adolphe Merkle Institute (AMI; Fribourg, Switzerland; www.ami.swiss), together with international collaborators, have pioneered a novel method for creating thin, energy-converting membranes that mimic the structure and function of biological cell membranes. This discovery, described in a recent issue of *Nature*, could have significant applications in fields ranging from implantable artificial electric organs to water desalination.

The new technique leverages the interface of an aqueous two-phase system to form and stabilize these membranes. By carefully controlling the conditions under which two immiscible water-based solutions interact with the opposing sides of these membranes, the researchers created defect-free membranes that are just 35 nm thick and can cover areas larger than 10 cm^2.

The method employs block copolymers (BCPs), highly tunable polymers consisting of two or more distinct polymer segments, to form a bilayer at the interface of the two phases. The resulting membranes exhibit remarkable mechanical properties and self-healing capabilities, making them robust and durable for practical use.

These artificial membranes replicate the selective ion-transport functions of natural cell membranes. By incorporating a natural transport peptide, the membranes achieve high ion selectivity, allowing them to generate electric power from solutions of different salts. This functionality is inspired by the electric organs of rays and other electric fish, which use similar principles to generate power. Potential applications include energy storage, water desalination, medical treatment (dialysis) and even implantable electric-power sources. ■

LINEUP

Plant Watch

Trelleborg Group to construct new production plant in North Carolina

July 16, 2024 — Trelleborg Group AB (Trelleborg, Sweden; www.trelleborg.com) is investing in a new production facility to expand its business for engineered coated fabrics in Rutherfordton, N.C. In total, Trelleborg is investing more than SEK 300 million (around \$28 million) in the expanded facility. Groundbreaking is scheduled for the fourth quarter of 2024, with production starting in early 2026.

BP granted funding for 'green' hydrogen project at Lingen Refinery

July 15, 2024 — Bp plc (London; www.bp.com) has been granted funding to support the development of a green hydrogen project next to the bp Lingen Refinery in Germany. The project aims to install a 100-MW electrolyzer capable of producing an average of 10,000–11,000 metric tons per year (m.t./yr) of green hydrogen.

Evonik to expand sodium methylate production plant in Argentina

July 12, 2024 — Evonik Industries AG (Essen, Germany; www.evonik.com) has expanded sodium methylate production capacity at its Rosario plant in Argentina. The move is in response to growing demand for biofuels in the region and will see the annual capacity increase by 50%, from around 60,000 m.t./yr to 90,000 m.t./yr. Expanded production of high-performance sodium methylate catalysts aims to significantly increase biodiesel productivity.

Kemira expands ferric chloride capacity in Spain

July 9, 2024 — Kemira Oyj (Helsinki, Finland; www.kemira.com) is expanding its ferric chloride production capacity in Tarragona, Spain to enable production of specific biogas digestion products (BDP). Ferric chloride is also the most commonly used coagulant for phosphorus reduction in wastewater treatment. The capacity expansion is planned to begin operation sometime during 2026.

Eramet inaugurates direct lithium-extraction plant in Argentina

July 8, 2024 — Eramet Group (Paris, France; www.eramet.com) inaugurated and started commissioning work at its Centenario direct lithium-extraction (DLE) plant in Salta Province, Argentina, becoming what is said to be the first European company to produce battery-grade lithium carbonate at industrial scale. First production is expected in November 2024. Centenario Phase 1 is designed to extract and produce 24,000 m.t./yr of battery-grade lithium carbonate at full capacity.

AkzoNobel starts up new coatings production line in China

July 8, 2024 — AkzoNobel N.V. (Amsterdam, the Netherlands; www.akzonobel.com) announced that a newly updated and automated production line is up and running at the company's Suzhou site in China, part of a €14-million investment designed to double the plant's capacity for marine and protective coatings by 2025. The recent upgrade, which will already boost daily capacity by more than 40%, is scheduled to be followed by updates to three additional lines. This will result in the doubling of overall capacity before the end of next year.

PKN Orlen completes revamp project to double ethylene and propylene capacities

July 3, 2024 — PKN Orlen (Płock, Poland; www.orlen.pl) has completed the Olefin II revamping project, an investment which has allowed the company to double its ethylene and propylene streams. The modernized plants are capable of producing up to 700,000 m.t./yr of ethylene and up to 385,000 m.t./yr of propylene. The bulk of the output will be streamed to new plants operated by Basell Orlen Polyolefins and Anwil Wloclawek.

Trinseo opens PMMA depolymerization facility in Italy

July 1, 2024 — Trinseo plc (Berwyn, Pa.; www.trinseo.com) has opened its polymethyl methacrylate (PMMA) depolymerization facility in Rho, Italy. Trinseo's PMMA depolymerization facility utilizes an advanced continuous process to produce high-purity regenerated MMA from pre- and post-consumer acrylic materials.

Phillips 66 achieves full production rates of renewable fuel at Rodeo Complex

July 1, 2024 — Phillips 66, Inc. (Houston; www.phillips66.com) announced the full conversion of the Rodeo Renewable Energy Complex, expanding to commercial-scale production. The Rodeo facility in the San Francisco Bay Area increased rates to approximately 50,000 bbl/d (800 million gal/yr), reaching the company's goal of achieving full capacity by the second quarter of 2024.

Elkem to pilot CO_2-free silicon production with support from Enova

July 1, 2024 — Elkem ASA (Oslo, Norway; www.elkem.com) plans to deploy a new concept for silicon production, which eliminates nearly all direct CO_2 emissions. The concept involves capturing and recycling the carbon in the process offgas and reusing it in the production process. Enova SF (www.enova.no) has granted Elkem NOK 31 million (around \$2.9 million) for a medium-scale pilot located in Kristiansand, Norway.

Look for more latest news on chemengonline.com

Mergers & Acquisitions

Aramco to acquire stake in APQ's Blue Hydrogen Industrial Gases

July 16, 2024 — Aramco (Dhahran, Saudi Arabia; www.aramco.com) agreed to acquire a 50% interest in the Jubail-based Blue Hydrogen Industrial Gases Co. (BHIG), a wholly owned subsidiary of Air Products Qudra (APQ), a joint venture (JV) between Air Products and Qudra Energy. The transaction will also include options for Aramco to offtake hydrogen and nitrogen.

Honeywell to acquire Air Products' LNG business for $1.81 billion

July 10, 2024 — Honeywell International, Inc. (Charlotte, N.C.; www.honeywell.com) agreed to acquire Air Products' (Lehigh Valley, Pa.; www.airproducts.com) liquefied-natural-gas (LNG) business for $1.81 billion. The acquired LNG business includes in-house design and manufacturing of coil-wound heat exchangers (CWHE) and related equipment. Air Products' LNG Business has headquarters in Allentown, Pa. and a 390,000-ft^2 manufacturing facility in Port Manatee, Fla.

TotalEnergies acquires used-oil regeneration specialist Tecoil

July 8, 2024 — TotalEnergies S.A. (Paris, France; www.totalenergies.com) acquired Tecoil, a Finnish company specialized in the production of re-refined base oils (RRBOs). RRBOs are used oils that are treated to give them properties comparable to virgin base oils. Tecoil currently operates a 50,000-m.t./yr facility for RRBOs in Hamina, Finland. Tecoil has developed its own circular network for collecting used lubricants in Europe to supply its plant.

Kemira announces acquisition of Norit's reactivation business

July 2, 2024 — Kemira has agreed to purchase Norit's U.K. activated-carbon reactivation business from Purton Carbons Ltd. This acquisition is the first step for Kemira in entering the market for micropollutants removal, as activated carbon is the most common technology to treat micropollutants in water-treatment applications. The scope of the agreement includes a reactivation facility in Purton, U.K.

Saint-Gobain to acquire Fosroc for over $1 billion

July 1, 2024 — Saint-Gobain S.A. (Courbevoie, France; www.saint-gobain.com) plans to acquire Fosroc, a privately owned construction chemicals firm for $1.025 billion (around €960 million). Headquartered in Dubai, Fosroc provides a wide range of products, including admixtures and additives for concrete and cement, adhesives and sealants, waterproofing, concrete-repair solutions and flooring.

DuPont to acquire contract manufacturer Donatelle Plastics

July 1, 2024 — DuPont (Wilmington, Del.; www.dupont.com) announced that it is acquiring Donatelle Plastics Inc. (New Brighton, Minn.), a contract manufacturer specializing in the design and production of medical components and devices. Dontelle will provide DuPont with expanded technologies, such as medical-device injection molding, liquid silicone-rubber processing, precision machining, device assembly and tool building. ■

Mary Page Bailey

Public-Private Partnerships Spur Decarbonization Efforts

Government programs, such as the Industrial Demonstrations Program (IDP) in the U.S., are helping to advance commercial-scale decarbonization strategies including thermal energy storage, CO_2 utilization and electrification

As the world continues to grapple with climate change, companies' strategies for managing carbon emissions, adapting to regulatory changes, and transitioning to a low-carbon economy are becoming key indicators of resilience and competitiveness. Decarbonization — the phasing out of greenhouse gas (GHG) emissions from the industrial sector — has emerged as a critical aspect of future business operations in sectors like the chemical process industries (CPI). With wide diversity in its energy inputs and processes, the CPI occupy a unique position: they are simultaneously drivers of the transition to low-carbon energy, producing chemicals and materials that enable other clean-energy industries to decarbonize, while also working to incorporate decarbonization strategies in their own manufacturing operations.

The progress of the Industrial Demonstrations Program (IDP) — administered by the Office of Clean Energy Demonstrations (OCED) at the U.S. Department of Energy (DoE; Washington, D.C.; www.energy.gov) — provides examples of how governmental funding support is helping to spur large-scale industrial decarbonization projects across the CPI. While the IDP is only one part of a wider movement, the projects highlight several approaches that are likely to be important to expanding decarbonization of hard-to-abate sectors in the future: thermal energy storage; use of waste carbon dioxide (CO_2) as a feedstock; and electrification of process-heat technologies.

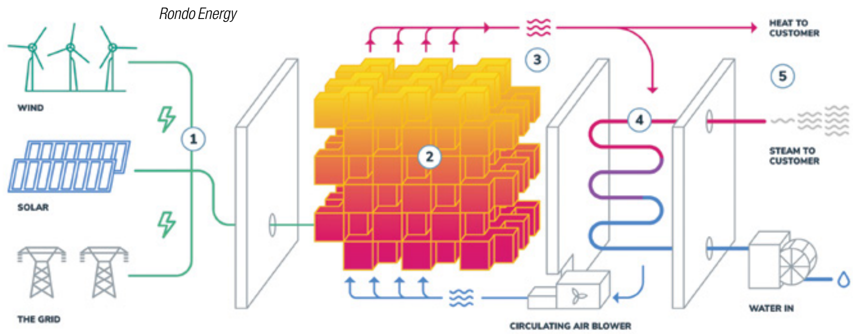


FIGURE 2. Heat batteries, developed by Rondo Energy, will be used in beverage making to replace natural-gas-fired heat in one of the IDP projects

FIGURE 1. Eastman is building two PET-recycling facilities, similar to this one in Tennessee, that will lower emissions with thermal energy storage

Public-private partnerships

This spring, the DoE announced the selection of 33 projects for IDP award negotiations using $6.3 billion in program funding. Funded by U.S. legislation (the Bipartisan Infrastructure Law and the Inflation Reduction Act), the IDP projects are structured as collaborative public-private partnerships in which the selected projects are eligible for a federal cost share of up to 50% of the project cost (non-federal cost share must be at least 50% of the total). According to a DoE spokesperson, IDP projects are aimed at four overarching goals: "deep decarbonization (50–75% emissions reduction per project); timeliness (performance period this decade); market viability (spur follow-on investment in lower-embodied carbon goods); and community benefits (greatest benefit for the most people)." The projects feature a range of approaches to decarbonization, including energy efficiency, industrial electrification, low-carbon fuels, feedstock changes, energy sources including clean hydrogen, material efficiency or substitution, carbon capture utilization and storage, and others.

The goal is to advance deep-decarbonization technologies to technology readiness level (TRL) 9 by the projects' end, DoE says. Negotiations between the DoE and the selected companies are currently in progress.

A table showing all 33 selected projects under the IDP can be found on p. 14.

Thermal energy storage

Recycling of plastic waste has emerged as a central theme of industrial sustainability, but to make a large impact on industrial GHG emissions, the energy required for the recycling process needs to be reduced as well. One of the IDP projects is an example of this. The Polyethylene Terephthalate (PET) Recycling Decarbonization Project, led by Eastman

Chemical Co. (Kingsport, Tenn.; www.eastman.com), plans to construct a first-of-a-kind molecular-recycling facility in Longview, Tex. capable of taking products that are typically landfilled or incinerated, like polyester trays, colored and opaque bottles and polyester fabrics and turning them into virgin-quality PET — a material that is heavily used for packaging, film and fiber applications. The facility plans to use thermal energy storage, powered by on-site solar power, to decarbonize process heating operations by storing heat for use in the process, such as heating heat-transfer fluids and heating boilers (lowering the need for natural gas).

This will result in a product with 70% lower carbon intensity than fossil-derived virgin PET, and approximately a 90% reduction when including avoided incineration emissions, Eastman says. The thermal battery technology at this scale represents a cross-cutting opportunity to electrify and decarbonize high-temperature process heat across industry sectors, DoE says.

Chris Layton, director of sustainability, specialty plastics, at Eastman explains that the company's molecular recycling process for polyesters, including PET, uses a methanolysis process, where methanol is used as a reactant to convert PET into the monomers dimethyl terephthalate (DMT) and ethylene glycol. The monomers yielded by plastic waste are purified before repolymerizing them into plastics that are indistinguishable from those originating directly from petroleum, Layton says.

The process can tolerate some contaminants, such as polyvinyl chloride or polyethylene, but works ideally with 95+%-pure PET. Finished PET from recycled plastics result in 20-30% lower greenhouse gas emissions than making the plastics from petroleum, mostly from the elimination of the need to extract, transport and refine the petroleum. Eastman's methanolysis technology stems from process technology first developed to recycle X-ray film from the company's earlier history in films and photography.

In April, Eastman announced the Longview site, as well as another facility in the Normandy region of France. Both facilities will eventually produce about 110,000 metric tons per year of PET from recycled PET waste. Eastman currently uses the methanolysis process for recycling bottles at its Kingsport facility (Figure 1).

The new facilities with the thermal energy storage technologies are currently in the engineering phase and are expected to come online in 2027 (Texas) and 2028 (France). Layton says that the decarbonization of process heating at the new facilities will lower the CO_2 generation from 2.2 kg of CO_2 per kg of PET resin produced (at Eastman's original PET-recycling facility at Kingsport) to about 0.6 kg CO_2 per kg of PET resin produced. The DoE OCED grant of up to $375 million (the total is still being negotiated) will be used to accelerate the scaling of the thermal battery technology.

The recycled PET feedstock for the plants will come from local regions, in an approach Layton calls regional circularity, both from local materials recovery centers (MRFs), as well as waste from other PET recyclers, and

TABLE 1. DOE OFFICE OF CLEAN ENERGY DEMONSTRATIONS (OCED) INDUSTRIAL DEMONSTRATIONS PROGRAM (IDP) AWARD SELECTIONS				
Lead organization	**Location**	**Industrial category**	**Description**	**Federal cost share maximum**
Wieland North America Recycling	Shelbyville, Ky.	Aluminum and metal	Advanced copper recycling	$270 million
Century Aluminum Co.	TBD; prefer Kentucky or Ohio/ Mississippi river basins	Aluminum and metal	Green aluminum smelter	$500 million
Constellium	Ravenswood, W.Va.	Aluminum and metal	Low-carbon SmartMelt furnace conversion	$75 million
Golden Aluminum	Fort Lupton, Colo.	Aluminum and metal	NextCast: next-generation aluminum mini mill	$22.3 million
Real Alloy Recycling	Wabash, Ind.	Aluminum and metal	Zero-waste Advanced Aluminum Recycling	$67.3 million
Brimstone Energy Inc.	TBD	Cement and concrete	Deeply Decarbonized Cement	$189 million
Sublime Systems Inc.	Holyoke, Mass.	Cement and concrete	First commercial electrochemical cement manufacturing	$86.9 million
National Cement Company of California Inc.	Lebec, Calif.	Cement and concrete	Lebec net-zero plant project	$500 million
Roanoke Cement Co. LLC	Troutville, Va.	Cement and concrete	Limestone calcined clay cement production	$61.7 million
Summit Materials Inc.	Port Deposit, Md.; McIntyre, Ga.; Elmendorf, Tex.; Sulphur Springs, Tex.	Cement and concrete	Low-carbon calcined clay cement demonstration	$215.6 million
Heidelberg Materials US, Inc.	Mitchell, Ind.	Cement and concrete	Mitchell Cement Plant decarbonization project	$500 million
ExxonMobil Corp.	Baytown, Tex.	Chemicals and refining	Baytown olefins plant carbon reduction project	$331.9 million
ISP Chemicals LLC (Ashland Co.)	Calvert City, Ky.	Chemicals and refining	Chemical production electrification and heat storage	$35.2 million
Dow Chemical Co.	U.S. Gulf Coast	Chemicals and refining	Novel CO_2 utilization for electric vehicle battery chemical production	$95 million
Eastman Chemical Co.	Longview, Tex.	Chemicals and refining	Polyethylene terephthalate (PET) recycling decarbon-ization	$375 million
Orsted P2X US Holding	Texas Gulf Coast	Chemicals and refining	Star e-Methanol for using captured CO_2 to produce methanol	$100 million
T.EN Stone & Webster Process Technology Inc.	U.S. Gulf Coast	Chemicals and refining	Sustainable ethylene from CO_2 utilization with renewable energy	$200 million
BASF Corp.	Freeport, Tex.	Chemicals and refining	Syngas production from chemical byproduct streams	$75 million
International Paper Co.	Mansfield, La.	Pulp and paper	Pulp and paper energy efficiency and electrification	$46.6 million
Unilever	Covington, Tenn.; Sikeston, Mo.; St. Albans, Vt.; Waterbury, Vt.	Food and beverage	Decarbonization of ice cream manufacturing using electric boilers and industrial heat pumps	$20.9 million
Kraft Heinz	Champaign, Ill. and multiple others	Food and beverage	Decarbonization through integrated electrification and energy storage	$170.9 million
Diageo Americas Supply Inc.	Shelbyville, Ky. And Plainfield, Ill.	Food and beverage	Heat batteries for deep decarbonization	$75 million
Libby Glass	Toledo, Ohio	Glass	Flexible fuel electric hybrid glass furnace demonstration	$45.1 million
O-I Glass Inc.	Tracy, Calif.; Zanesvillle, Ohio; Toano, Va.	Glass	Glass furnace decarbonization technology	$125 million
Gallo Glass Co.	Modesto, Calif.	Glass	Hybrid electric glass furnace	$75 million
Skyven Technologies	TBD	Process heat	Steam-generating heat pumps for cross-sector decarbonization	$145 million
Kohler	Casa Grande, Ariz.	Process heat	Vikrell electric boiler and microgrid system	$51.2 million
SSAB	Perry County, Miss. and Montpelier, Iowa	Iron and steel manufacturing	Hydrogen-fueled zero-emissions steel making	$500 million
Cleveland Cliffs Steel Corp.	Middletown, Ohio	Iron and steel manufacturing	Hydrogen-ready direct reduced iron plant and electric melting furnace installation	$500 million
American Cast Iron Pipe Co.	Birmingham, Ala.	Iron and steel manufacturing	Induction melting upgrade	$75 milion
U.S. Pipe and Foundry Co.	Bessemer, Ala.	Iron and steel manufacturing	Iron electric induction conversion	$75.5 million
Vale USA	U.S. Gulf Coast	Iron and steel manufacturing	Low-emissions, cold-agglomerated iron ore briquette production	$282.9 million
Cleveland-Cliffs Steel Company	Lyndora, Pa.	Iron and steel manufacturing	Steel slab electrified induction reheat furnace upgrade	$75 million

polyester fibers from carpet recycling efforts, such as those in California. The PET recycling plants have already secured offtake agreements with beverage companies like Pepsi-Co, Layton says.

Several other examples of IDP projects using heat storage for decarbonization include the following:

ISP Chemicals, LLC, an Ashland Company (Wilmington, Del.; www.ashland.com). ISP leads the Chemical Production Electrification and Heat Storage project, along with the Tennessee Valley Authority (www.tva.com) and Electrified Thermal Solutions (ETS; Medford, Mass.; www.electrifiedthermal.com). The project's intent is to replace natural gas boilers with electric heat delivered with a thermal battery, reducing GHG emissions associated with steam generation by nearly 70% at Ashland's Calvert City, Ky. chemical plant. This project intends to demonstrate electrification with thermal heat storage using ETS's Joule Hive system. The Joule Hive is based on electrically conductive bricks made from a proprietary alumina chromium material that is subjected to doping techniques to increase electrical conductivity. The bricks can achieve near flame temperatures while resisting oxidative breakdown. The project is designed to demonstrate the ability to navigate current challenges with electrification of high-temperature thermal processes, including reliability, efficiency improvements, and the ability to leverage affordable off-peak electricity rates for a 24/7 operation, DoE says.

Kraft Heinz. The Delicious Decarbonization Through Integrated Electrification and Energy Storage project, led by Kraft Heinz (Chicago, Ill.; www.kraftheinzcompany.com), plans to upgrade, electrify, and decarbonize its process heat at 10 facilities by applying a range of technologies including heat pumps, electric heaters, and electric boilers in combination with biogas boilers, solar thermal, solar photovoltaic, and thermal energy storage. The company expects that the tailored application of these technologies at each facility will reduce overall energy use by 23% and natural gas use by 97%, leading to a reduction in annual CO_2 emissions by more than 300,000 metric tons.

Diageo Americas Supply Inc. In the Heat Batteries for Deep Decarbonization of the Beverage Industry project, Diageo Americas Supply, Inc. (New York; www.diageo.com) plans to partner with Rondo Energy Inc. (Alameda, Calif.; www.rondo.com) and the National Renewable Energy Laboratory (Golden, Colo.; www.nrel.gov) to replace natural gas-fired heat with Rondo Heat Batteries powered by onsite renewable energy and electric boilers at facilities in Shelbyville, Ky. and Plainfield, Ill. Rondo's heat batteries use wind or solar power to heat electric heating elements and warm surrounding bricks and store the energy for days with heat losses of less than 1% per day (Figure 2). This project will demonstrate an industrial-heat-and-power model system that could be replicated in many other sectors, as well as food and beverage more broadly, Rondo says. These upgrades would reduce carbon emissions by nearly 17,000 metric tons per year to decarbonize the production facilities for a variety of alcoholic beverages.

Incorporating CO_2 utilization

Carbon-capture technologies have become more widespread (see *Chem. Eng*., October 2022; pp. 13–18), but piping the CO_2 for permanent underground storage can present its own challenges. In many situations, it is more ideal to utilize captured CO_2 as a feedstock for other processes. There are several examples of this within the IDP selectees.

Dow Chemical CO_2 utilization for EV battery chemicals. Led by Dow (Midland, Mich.; www.dow.com), this project plans to design and construct a facility on the U.S. Gulf Coast to capture and utilize approximately 100,000 tons of CO_2 per year to produce essential components of electrolyte solutions needed for domestic lithium-ion batteries, according to DoE. This project would demonstrate the capture and utilization of more than 90% of the CO_2 from ethylene oxide manufacturing for use in making carbonate solvents for batteries for electric vehicles and energy storage. Carbonate solvents help enhance battery performance and longevity, Dow says.

Ørsted P2X US Holding LLC. The Star e-Methanol project, led by a U.S. subsidiary of Ørsted A/S (Fredericia, Denmark; www.orsted.com), plans to use captured CO_2 from a local industrial facility to produce e-methanol for marine shipping fuel, or as an input for sustainable aviation fuel. The project consists of multiple components that when combined, lead to a net-neutral CO_2 solution, Ørsted says. This includes building new onshore wind and solar projects in Texas to power the electrolysis of green hydrogen, capturing biogenic carbon from an industrial facility, and synthesizing the captured biogenic carbon with green hydrogen to create e-methanol. The resulting e-methanol will reduce CO_2 emissions by more than 90% compared to conventional marine fuel, the company says. The facility will produce up to 300,000 metric tons of e-methanol per year, DoE adds.

Sustainable ethylene from CO_2 utilization with renewable energy (SECURE). The SECURE project, led by T.EN Stone & Webster Process Technology Inc. in partnership with LanzaTech (Skokie, Ill.; www.lanzatech.com), plans to demonstrate an integrated process to utilize captured CO_2 from ethylene production and convert it to ethanol using LanzaTech's Gas Fermentation technology. Ethanol will be further converted into sustainable ethylene utilizing Technip Energie's Hummingbird technology. Project SECURE will be sized for 50,000 tons of annual ethanol production, which will enable 30,000 tons of annual ethylene production, LanzaTech says.

Electrification

Several IDP projects selected for award negotiations involve electrification of various parts of processes that have traditionally been powered by fossil fuels. Here are some examples of this from the food, paper and glass sectors.

Unilever USA. The Decarbonization of Unilever (Englewood Cliffs, N.J.; www.unilever.com) Ice Cream Manufacturing project plans to replace natural gas boilers with electric boilers and industrial heat pumps using waste heat recovery across four ice cream manufacturing facilities in Tennessee, Missouri and Vermont. The facility upgrades are expected to reduce CO_2 emissions by more than 14,000 metric tons per year, DoE says, with a pathway to address 100% of heat-related process emissions. Along with reduced emissions, this project has an extremely high replicability potential and will create a model that could lead to further decarbonization throughout the food and beverage sector where approximately 50% of processing emissions are from low-temperature heating, DoE says.

Libbey Glass. The Flexible Fuel Electric Hybrid Glass Furnace Demonstration project, led by Libbey Glass (Toledo, Ohio; www.libbey.com) plans to replace four regenerative furnaces with two larger hybrid electric furnaces to reduce an estimated 60% of CO_2 emissions associated with the manufacturing of glass tableware products at Libbey's facility in Toledo. Hybrid glass furnaces combine the energy from fuel combustion (mostly natural gas) with a highly increased proportion of electric power. The benefits of oxygen fuel with electric melting include replacing up to 80% of the melting energy with renewable-sourced electricity, DoE says.

Gallo Glass Co. Gallo Glass (Modesto, California; www.galloglass.com) also received an award to install a hybrid electric furnace that will reduce natural gas use by 70% and increase recycled glass content by 30% in its glass bottle production process.

O-I Glass. The Glass Furnace Decarbonization Technology project plans to rebuild four furnaces across three facilities in California, Ohio and Virginia to reduce Scope 1 CO_2 emissions by an estimated 48,000 metric tons per year. The proposed rebuilds combine five furnace technologies on each furnace, marking the first time that all five technologies have been implemented simultaneously, DoE says. The technologies reduce waste heat and increase electrification, aiming to combine multiple technologies and use them with different glass colors and container types.

International Paper Company. In the Pulp and Paper Energy Efficiency and Electrification Upgrades project, International Paper Company (IP; New York, N.Y.; www.internationalpaper.com) and Via Separations (Watertown, Mass.; www.viaseparations.com) are partnering to decarbonize a thermal process at IP's Mansfield, La. site using Via's novel membrane-based technology. Via's membrane technology uses graphene-oxide-based membranes to replace thermal separations with mechanical separations in removing water in pulp production. The project expects to reduce 75% of CO_2 emissions per gallon of clean water removed. This project plans to not only reduce the facility's GHG emissions but also to demonstrate the credibility of the membrane technology to scale across the 130 domestic pulp-and-paper mills and other industrial sectors, DoE says.

For more information on IDP, including projects in cement and concrete, as well as other decarbonization efforts not included in the IDP, see the online version of this article at www.chemengonline.com. ■

Scott Jenkins

Understanding Energy Efficiency in a Fired Heater

Department Editor: Scott Jenkins

Process heating systems are critical parts of chemical process industries (CPI) facilities. Unfortunately, the reliable, efficient operation of utility systems is often taken for granted, and they receive little engineering attention. This is perhaps understandable, since these systems play a supporting role to a generally more complex, attention-demanding process. However, utility systems are inherently close to the energy consumption of a facility, and their correct operation is critical to reduce energy costs and CO_2 emissions of a process. The simplicity of these systems means engineering analysis is often quick and effective, so occasionally analyzing these systems to ensure they are operating as designed, and to evaluate if large improvements are possible with new technologies, can bring significant benefits. A powerful but simple engineering tool — the mass and energy balance — provides the correct framework to understand and improve the efficiency of a process heating system.

Inputs and outputs

Often a very complicated system can be analyzed by treating it as a black box and focusing on all the input and output streams. Figure 1 shows a fired heater and all the input and output streams. Evaluating these streams with thermodynamics can determine the thermal efficiency of a fired heater. For a combustion system, efficiency is usually defined as the ratio of available heat (heat that performs useful work within the process) to the gross heat input of the fuel burned. That value is the fuel's higher heating value — 55,500 kJ/kg for methane, which closely approximates high-quality natural gas.

Stack losses

A rigorous mass-energy balance would quickly uncover that a substantial portion of the heat of combustion is escaping out the stack of the fired heater. That makes sense of course — for every 1 kg of methane burned, 18.1 kg of fluegas exit the stack — that's a lot of mass and a lot of potential for heat to be carried out of the stack. Indeed, the fluegas temperature indicates how much heat is escaping out of the stack, and it is one of the most important variables that determines the efficiency of a fired heater. An efficient heater will have fluegas not much hotter than about 200°C, a limit set by the acid dew point. Heat recovery below that temperature is possible, but expensive, requiring special alloys to avoid corrosion. An efficient, ideal system with a fluegas temperature of 200°C has stack losses of only 16% — implying a thermal efficiency of 84% (stoichiometric air-to-fuel ratio, methane combustion). That is about as efficient as can be achieved economically. In older or less efficient systems, fluegases may be at 500°C — such a system has stack losses of 28% and a thermal efficiency of 72%. The second system would have about 17% higher fuel consumption and CO_2 emissions than the first. For a 1-MW system, that amounts to $11,000/yr in additional natural gas expenses and 310 m.t./yr of CO_2 emissions (assuming a natural gas price of $2/million BTU).

Air input stream

The other key stream to understand from the mass balance is the air input stream. The flowrate of this stream is not measured in most systems, so it's generally calculated using the fluegas oxygen content. Excess oxygen in the fluegas allows calculation of how much excess air was used in the combustion process. Excess air must be warmed up to the combustion temperature, then leaves the system carrying some of the valuable heat of combustion with it. In a natural-draft fired heater, operating at 2–3% excess oxygen (measured on a dry basis) is typical, but any higher than this is a sign that the system could have its efficiency improved.

If a mass-energy balance reveals that a system has unacceptable stack losses, one solution is to add a waste-heat recovery system. The goal of this system is to reduce the fluegas temperature and use the recovered heat to displace heat demand elsewhere in the process. Particularly as systems get larger, the potential for natural gas savings quickly justifies the capital cost of a simple waste-heat recovery system.

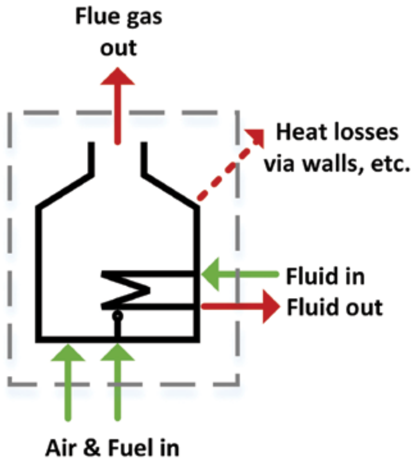


FIGURE 1. Identify input and output streams to perform a mass-energy balance for a fired heater

Waste-heat recovery often uses synthetic heat-transfer fluid (HTF) systems, which are generally very cost effective, avoiding the capital and maintenance expenses of water treatment systems needed for steam. In addition, synthetic fluids are thermally stable to very high temperatures, suitable for hot fluegases, and will remain fluid at cold temperatures, so freeze protection is generally not required. For example, one widely used HTF has a maximum bulk temperature of 380°C and remains pumpable (viscosity 2,000 cSt) down to –14°C. ■

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Editor's note: The content shown here was prepared by Kent B. Fischer, Ph.D., Eastman Chemical Co., 200 S. Wilcox Dr, Kingsport TN 37660, USA

Focus on Mobile Devices

Updated digital technology to support field workers

The updated Ability Connected Worker technology (photo) offers new functionalities that strengthen and accelerate the digitalization of the field-operator experience to mitigate the risk of human error and unscheduled downtime. The enhanced software integrates technology and connectivity into the workplace to provide the operator more flexibility, control and ease-of-use through greater visibility of real-world circumstances and data. The Integrated Task Manager application (app) will deliver ongoing, continuous improvements on current data and stronger analysis capabilities on historical data, allowing operators to more accurately measure their performance efficiency. Improvements in the Procedure Manager app mean that operators can now preview their industrial procedures across various mobile devices and in different virtual settings. The updated Mobile app features an improved audit trail and the ability to go back and enter or approve data in a more controlled way. The improved visibility allows for better prioritization and ease-of-use, increasing quality of operations as a result. — *ABB, Zurich, Switzerland*
www.abb.com

ABB

A new tablet for use in hazardous areas

Pad-Ex 01 P12 (photo) is a new tablet for professional use in hazardous areas in Zone 2/22, Division 2. The tablet is equipped with the Windows 11 Pro 64-bit operating system, thus offering maximum efficiency for demanding tasks. It has an ultra-thin and lightweight housing with a widescreen display and is while remaining durable. Thanks to its compact and lightweight design, the device is ideal for outdoor use. The Pad-Ex 01 P12 is said to be the first explosion-proof tablet to support powerful applications due to the 12th-generation Intel Core i5 processors based on the Intel Alder Lake platform, enabling a particularly high level of performance. The tablet works significantly faster than previous models with 8th-generation processors. The model is also equipped with modern Intel Iris Xe graphics. This provides sufficient computing power to process large amounts of data, images and video feeds in real time. — *Pepperl+Fuchs SE, Mannheim, Germany*
www.pepperl-fuchs.com

Pepperl+Fuchs

A smartphone with multitasking capabilities

Introduced last October, the RG880 smartphone (photo) is equipped with the PTT/MCPTT-optimized Snapdragon 680 4G Mobile Platform from Qualcomm Technologies, and supports 3GPP Release 12. The Android 13 rugged device is slim in design and has been completely adapted to the needs of users, with a large PTT button on the side, an SOS button for lone worker use (via third-party LWP app) and a switch button for individual or group push-to-talk (PTT) calls, as well as other freely assignable buttons. A clear 5.5-in. screen, a new, innovative speaker design and a fingerprint sensor complete the feature package. The powerful Snapdragon 680 4G Mobile Platform supports optimized transmission of voice, video and data information. — *RugGear GmbH, Lauda-Koenigshofen, Germany*
www.ruggear.com

RugGear

This gateway has a revamped Argos cloud interface

The new Netbiter EC360W gateway (photo) now comes with a fully revamped graphical user interface for Netbiter Argos Cloud to enhance user experience. This new model includes a diversity antenna, making it more robust and ensuring better connectivity in harsh environments. Additionally, the launch of the Netbiter Argos app will improve how service teams manage notifications. With push notifications that can be sent and acknowledged via the app, service teams can now utilize these alerts to their fullest potential. The EC360W connects field equipment to the Argos cloud via Cellular 4G or Ethernet, facilitating seamless data exchange. The device's dual-antenna setup ensures reliable

HMS Networks

Bartec Top Holding

i.safe Mobile

ProComSol

Werock Technologies

communication even in the most challenging conditions. The cloud platform displays data via both the web and the new Argos mobile app. With the new Argos mobile app, users will now be able to respond to alarms faster and more efficiently, enhancing the monitoring capabilities and responsiveness of this management system. — *HMS Networks AB, Halmstad, Sweden*
www.hms-networks.com

Two smart devices for EX1 hazardous areas

The new SP9EX1 Smartphone and SC9EX1 Smartscanner (photo) are compact, lightweight and high-performing devices, bringing safety to EX1 (Zone 1/21 and Division 1/Class 1) hazardous areas. The SP9EX1 Smartphone is said to be the world's most compact 5G device in its class, with a 48 Megapixel main camera for imaging and an 8 Megapixel front camera for video calls, two configurable keys, dual loudspeakers for clear audio and a full range of accessories from charging stations to carrying solutions. SC9EX1 Smartscanner adds scanning efficiency and accuracy through the seamless integration with the Zebra SE55 Advance Range Scan Engine. The SC9EX1 integrated Zebra scan engine is configurable through the onboard settings application and through push configurations for fleet deployments. Both devices deliver all-day productivity and ergonomic design for one-hand use, while retaining a large 6.11-in. display. — *Bartec Top Holding GmbH, Bad Mergentheim,Germany*
www.bartec.com

Intrinsically safe head-mounted wearable for hazardous areas

This company and RealWear, Inc. recently launched with the RealWear Navigator Z1 (photo), which is said to be the world's most advanced intrinsically safe and ATEX/IECEx certified head-mounted wearable. Navigator Z1 is designed for use in hazardous areas for troubleshooting equipment via remote expert guidance, virtual training and for virtual workers using Field Services Management (FSM) or streamlined inspection-data-management systems (IDMS). The Navigator Z1 is powered by an advanced chipset with a built-in advanced artificial intelligence (AI) engine. Navigator Z1 ensures voice recognition for fully hands-free use up to 100 dBA, an essential feature for noisy oil-and-gas work environments. — *i.safe Mobile GmbH, Lauda-Koenigshofen, Germany*
www.isafe-mobile.com

HART and FF communicator kit for Android

This company recently released its new Android-based HART and Foundation Fieldbus (FF) communicator kit (photo). The kit includes all the items needed for a complete HART and FF communicator, including an Android tablet, HART and FF modem, communicator apps and carrying/storage case. The communicator apps use the Device Descriptor (DD) for the connected HART or FF device, so the user has full access to every Parameter and Method in the instrument. The Android apps, DevComDroid for HART and DevComFF.Droid for FF, in combination with the Softing mobiLink multi-protocol communicator (our PN: MOBI-FF), is a fully functional communicator. The entire DD Library for HART and FF devices from the FieldComm Group is included. New DDs can be added very easily by the user. A communicator that uses DD's can perform full configurations of Valves, Multi-Variable devices, and complex devices, such as radar level and Coriolis flowmeters. — *ProComSol, Ltd., Lakewood, Ohio*
www.procomsol.com

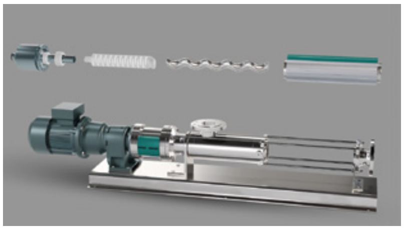
A compact, rugged tablet with extensive functionality

Released in April, the Rocktab U210 Pro rugged tablet (photo) is a 10-in. tablet that combines maximum performance and robustness in a compact housing and is aimed at professionals in demanding environments, such as field service, logistics and production. The Rocktab U210 Pro sets new standards in multitasking and performance. It is equipped with a 13th-generation Intel Core i5 processor with 10 cores and a powerful hybrid architecture. With 16 GB of LPDDR5 memory (32GB available on a project-by-project basis), the industrial tablet enables smooth operation even with complex processes. An ultra-fast NVMe SSD with up to 1 TB provides plenty of storage space for applications, images and documentation. — *Werock Technologies GmbH, Karlsruhe, Germany*
www.werocktools.com ■

Gerald Ondrey

New Products

AGI Glassplant UK



Netzsch Pumpen & Systeme

PSG Biotech

GEA

The next generation of pilot reactors launched at Achema

The Sakura and Sakura Mini next-generation premium pilot reactors (photo) incorporate the latest reactor-vessel technology to provide enhanced performance and efficiency for chemical process scaleup. Sakura includes vessels of up to 100 L, with the option to upgrade to this company's proprietary Ring Baffle Vessel Technology for optimal efficiency. Sakura Mini provides enhanced flexibility, with a range of interchangeable 10- to 30-L vessels in a customizable package. Both systems can support a wide range of applications, thanks to the ability to mount ancillary equipment — including condensers, reflux splitters, collection flasks and dropping funnels — directly to the frame. Both Sakura and Sakura Mini reactors can be seamlessly paired with the company's Pilot Reactor Controller for full workflow automation. — *AGI Glassplant UK Ltd., Royston, U.K.*
www.agi-glassplant.com

This progressing-cavity pump has been upgraded

The NEMO MY magnetically coupled pump (photo) is the latest upgrade of the NEMO progressing-cavity pumps. It was developed for more efficient and safer handling of media with high viscosities (up to 20,000 cP), such as slurries. However, using the NEMO MY not only means pumping safely, but also increases the efficiency of users' systems. Thanks to a magnetic coupling developed by this company and tailored to the requirements of progressing-cavity pumps, the NEMO MY pump can be operated at low speeds of 200 to 300 rpm. This means a significant reduction in the mechanical load and an extension of the service life of the drive system. — *Netzsch Pumpen & Systeme GmbH, Waldkraiburg, Germany*
pumps-systems.netzsch.com

Integral display transmitter offers instantaneous process metrics

The new SumoFlo CELE-8103-D integral display transmitter (photo) features a 144 mm x 144 mm, four-line display that can simultaneously show flowrate, totalized flow, temperature and product density. Available in both panel-mounted and tabletop configurations, the new transmitter is designed to work with all SumoFlo CPFM-8103 Series single-use Coriolis flowmeter models. The display transmitter is also designed for ease of use, with the unique capability to re-zero or reset the totalizer directly from the front panel. It provides users with instantaneous process metrics, enabling biopharmaceutical processors to identify and respond to process variations quicker, with fewer wasted materials and less downtime. — *PSG Biotech, Oakbrook Terrace, Ill.*
psgdover.com/biotech

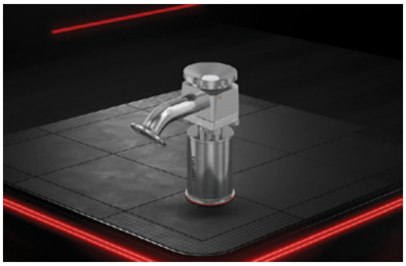
A new single-use perfusion separator

For the first time, perfusion disc separators for continuous production and faster processing can be implemented in biopharmaceutical cell-harvesting processes based on labor-saving, easy-to-use single-use devices. The newly introduced perfusion separators in this series (photo) offer the same advantages as classic disc separators for fed-batch processes. However, cleaning-in-place (CIP) and steam-in-place (SIP) cleaning is no longer necessary, meaning that the machine is ready for the next continuous process run in just a few minutes. In the kytero series, this company's disc technology has been implemented in particularly compact machines with an easy-to-handle single-use separation unit that contains the entire disc pack. This separating unit and all associated feed and discharge lines are simply replaced after a production run, thus offering maximum convenience and protection against contamination. The kytero separators are available for the smallest setups, to variants as large as 500 and 2,000 L. — *GEA AG, Düsseldorf, Germany*
www.gea.com

This non-invasive temperature sensor is SIL-2 certified

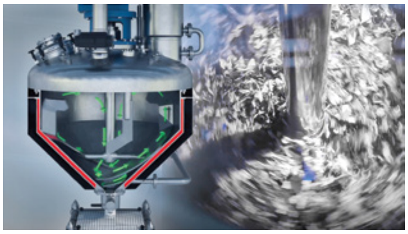
This company has launched an enhanced version of its Ninva TSP341-N non-invasive temperature sensor (photo, p. 24), which is said to be the first SIL2-certified non-invasive

ABB



GEMÜ Gebr. Müller Apparatebau

Pepperl+Fuchs



Ekato Systems

RenQuip

temperature transmitter. Using the surface temperature of the piping to infer the process temperature, Ninva provides the same level of accuracy and performance of an invasive measurement device without the risks and lifecycle costs associated with specification, installation and maintenance. Now SIL2-certified, NINVA TSP341-N is built on the TTH300 temperature transmitter. New features include a unique remote-mount configuration, improved resistance to vibration, optional configurations for applications up to 550°C, and simpler calibration and maintenance through extractable measuring insets with independent sensor calibration and trimming. Clamp collars for pipe diameters of 40 to 2,500 mm and special designs for diameters below 40 mm also avoid the need for complex thermowell designs for smaller pipes. — *ABB Ltd., Zurich, Switzerland*
www.abb.com

This tank-bottom valve is suitable for sterile applications

The pneumatically actuated P40 PD tank-bottom valve (photo) is designed for use in sterile applications. The sealing principle of the valve is based on the company's PD sealing technology, which hermetically separates the actuator from the medium. All actuator parts (except the sealing and design elements) are made from stainless steel. The valve has an optimized drain design. — *GEMÜ Gebr. Müller Apparatebau GmbH & Co. KG, Ingelfingen, Germany*
www.gemu-group.com

Ethernet-APL: A game changer for the CPI

Ethernet-APL fulfills the promise to bring digitalization to every corner of a process plant. The fast and efficient communication of large amounts of data is barrier-free and reliable in potentially explosive areas. At 10 Mbit/s, the transmission of enormous amounts of data over long distances is at least 300 times faster than with current technologies, such as HART or fieldbus. Users can therefore access information from highly diagnosable and configurable devices. The Ethernet-APL Rail Field Switch (photo) — the latest FieldConnex innovation — allows several applications to query information from the field simultaneously. Diagnostics via the physical layer itself makes it possible to detect and eliminate creeping quality deterioration and errors in the installation. The seamless insight of Ethernet APL technology helps to keep production quality and plant availability at a high level. The switch also reports physical layer measurements for fiber optic transmission. Specially developed modules connect the switch to the network via single-mode and multimode fiber optic cables. They support cable lengths of up to 30 km. They are certified as accessories for the switch and can be installed in Zone 2/Div. 2. — *Pepperl+Fuchs SE, Mannheim, Germany*
www.pepperl-fuchs.com

Efficient mixing and drying of battery recyclables

The Solidmix technology (photo) is suitable for the pre-drying of shredded battery scrap and has been optimized for the separation of the solvents contained in the batteries. By means of vacuum drying, the solvents can be quickly and reliably separated from the battery scrap. Continuous mixing of the material to be dried ensures optimal heat transfer and distribution in the equipment, which further increases the efficiency of the drying process. Due to the modular design of the dryers, it is possible to easily scale up to larger drying capacities. Usual capacities are in the range of 0.5–4 ton/h. The separation of the electrolytes facilitates the downstream hydrometallurgical treatment of the so-called black mass, which contains the valuable cathode and anode materials. — *Ekato Systems GmbH, Schopfheim, Germany*
www.ekato.com

Launch of a powerful flange spreader

The Viper-28 flange-spreading wedge (photo) is said to be the most powerful flange spreader in the world, boasting a spreading force of 28 metric tons and a precision tip measuring just 5 mm. This tool handles a wide range of applications for flanged joint maintenance, installation and commissioning. Despite its immense power, the Viper-28 weighs only 5 kg, combining lightweight design with formidable

strength. Its single-pin mechanism allows the entire tool to be disassembled by hand for simple and efficient maintenance. The Viper-28 is designed to assist in flange maintenance and prevent leakages. — *RenQuip Ltd., Aberdeen, Scotland*
www.renquip.com

New bulk-bag unloader discharges problematic materials

A new bulk-bag unloading station features a proprietary design that promotes the smooth, consistent, complete discharge of non-free-flowing materials. Developed for emptying difficult bagged powders and other bulk materials that cake, clump, bridge or generate nuisance dust, the new AFC BBU II (photo) uses dual, pneumatic steel paddles to gently coax the material through a new, extended-neck connection nestled inside an easy-access, oversized tie box. Complete discharge is assured while any potential dust particles are automatically captured by a built-in vacuum system to prevent release to the workplace. The AFC BBU II stands in a sturdy, steel frame that bolts to the floor to safely hold bulk bags with up 4,000 lb of material. — *Automated Flexible Conveyor, Inc., Clifton, N.J.*
www.afcspiralfeeder.com

Certified conveyor controllers promote safety, compliance

This company has earned the UL 508A certification for its pneumatic vacuum-conveyor controls (photo). Secured to support operator safety and help speed the conveyor installation process, the certification documents conformance with the National Electric Code (NEC) standard for the safe installation and electrical wiring of equipment in the U.S. and Canada. The conveyor controllers meet the UL 508A Industrial Control Panel Program requirements by featuring a high level of wiring and motor protection, quality electrical components and clear safety markings. — *Volkmann USA, Bristol, Pa.*
www.volkmannusa.com

Beer-foam separator reduces water wastage

The Beer Foam Separator (BFS 900; photo) is built to be used in combination with this company's GHS VSD+ screw vacuum pump. The BFS 900 was designed and developed in partnership with leading breweries and in direct response to the excess foam production that hampered the beer-filling process. The high amount of foam generated at the end of the filling process would enter the vacuum line and disrupt the process, leading to poor quality, reduced output. The CFS 900 actively solves the foam issue with its smart features and easy-to-maintain design, providing full protection to the vacuum pump and saving on costs, too. The BFS 900 is fabricated from 304 stainless steel with an auto-draining tank and associated logic control system. When the excess foam enters the vacuum system, it is effectively collapsed in the foam separator by a calming section with a large diameter for foam settling. The rising liquid level is detected by appropriate sensors and an automatic separation process is initiated by an airlock consisting of electro-pneumatic actuators and a receiver tank to enable drain in continuous operation. — *Atlas Copco Vacuum Technique, Cologne, Germany*
www.atlascopco.com

Tame turbulent flows with this conditioner

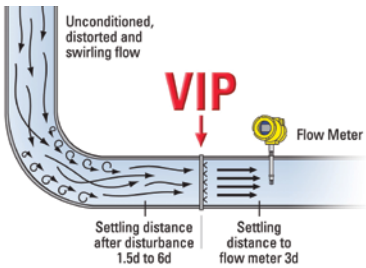
The Vortab Insertion Panel (VIP) flow conditioner (photo) features a unique design that maximizes flowmeter performance with minimal pressure drop in a simple-to-install, lightweight thin-panel design that overcomes turbulent pipe-flow profiles. The Model VIP blends the proven performance and low pressure-drop of the company's tab-type flow-conditioning technology with the low cost and ease-of-installation of an insertion panel-type flow conditioner. The tab-type flow-conditioning technology greatly reduces the pressure drop compared to alternative technologies, such as tube bundles, screens and perforated plates. Minimizing pressure drop is a significant design consideration in flow conditioning for process engineers to minimize plant energy consumption and energy costs, the company says. — *Vortab Co., San Marcos, Calif.*
www.vortab.com ■

Gerald Ondrey

Automated Flexible Conveyor

Volkmann USA

Atlas Copco Vacuum Technique



Vortab

Effective Dust Collection: Capturing Dust and Accounting for Loading

Three of the critical aspects of dust collection systems are properly identifying necessary dust capture points, effectively capturing dust at each point and accounting for solids loading in the ductwork. Key considerations for these aspects are presented here

Josh Marion
Jenike & Johanson, Inc.

IN BRIEF

DUST GENERATION AND CAPTURE POINTS

CONSIDER SOLIDS LOADING

CAPTURE THE DUST AT EACH POINT

Dust collection technology is used in nearly all manufacturing industries to reduce and capture fugitive dust. This is done for a variety of reasons, including to minimize respirable dust, to minimize the "fuel" for combustible-dust hazards, to meet environmental and workplace safety regulations, to remove unwanted fines and dust from a product stream, or otherwise just "keeping a clean house." Dust collection to reduce fugitive dust emissions is often used as an engineering control method to not only minimize dusts for the purposes stated above, but also to prevent dusts from one area of a process or facility from being transported to other areas or process equipment.

Although dust collection has been used since the 1800s, and is even more prevalent throughout industry today, dust collection systems often operate poorly because of improper design that does not properly account for the solids and their specific properties.

There are several important considerations associated with the design of dust-collection systems that require attention in order to ensure that the system successfully mitigates excessive dust releases and operates reliably without plugging. They are listed below:

1. To effectively capture dust at each collection point, identify not just the process' major fugitive-dust generation points, but the points where dust capture and collection is actually required.
2. When designing the dust-collection system, take into account the solids/dust loading in the ductwork.
3. Ensure reliable transport of the collected dust through the ductwork.
4. Ensure proper airflow balancing across the system.
5. Avoid plugging in both the ductwork and the filter.
6. Ensure the filter/collector is adequately designed to filter the dust from the air.
7. Ensure the air mover for the system (typically a fan) is adequately designed and sized for the application.
8. Consider dust hazards, including combustible-dust hazards, toxicological hazards and environmental hazards.

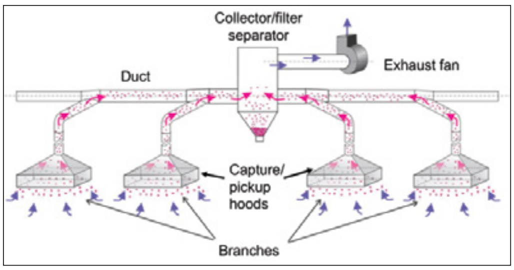


FIGURE 1. The diagram shows the components of a typical dust-collection sytem, including pickup points and ducting [*1*]

This article focuses on the first three of the above considerations, and discusses some common design mistakes. These include having unnecessary pickup points where dust capture and collection is not actually needed, failing to account for the solids loading in the design of the ductwork, and poor dust capture at each point where collection is required (often due to the hood being too far from the dust-generation point).

Dust generation and capture points

All dust collection systems, regardless of size and number of pickups, are dedicated systems that use vacuum pressure (suction) to capture dust from one or more localized points and accumulate the dust in another separate area. Dust collection systems all have four key components, illustrated in

FIGURE 2. The photo shows a dust-collection pickup on an enclosed silo headspace

Figure 1: one or more dust capture hoods/pickup points, the ductwork/piping, the solids disengagement/air cleaning device (the filter receiver or collector, often a baghouse) at the end of the ductwork, and the air mover (often a fan in dust-collection applications). All components need to work effectively and in concert for the dust collection system to perform successfully as designed. Unfortunately, dust collection systems don't always work as desired, and they can often wind up as a key bottleneck in a process.

Dust collection systems range in size, from large fixed and centralized systems that can have dozens of pickups (dust capture points) across several process areas, to smaller fixed systems with only a few dust pickups localized to specific processes or equipment, or mobile systems for "as required" point-of-use dust capture.

Fugitive dust may be generated or released in a variety of different industrial operations, as follows:

- Operations that tend to generate the most dust are those where there is high-energy, forceful mechanical breakdown of a material. Examples of this include comminution/particle-size-reduction equipment, such as crushing or milling, as well as grinding, sawing, sanding or polishing equipment.
- Operations that may release some dust include those where there may be leakage from equipment, for example, through shaft end seals of rotating equipment or leaky gaskets.
- Operations that tend to generate less dust include those where there is displaced air and entrainment of fine particles into air due to shaking, free-fall, or aeration, where particles can unintentionally break apart and generate more fines. Examples of this include screening, filling and discharge of bins, silos and hoppers, as well as bag filling or dumping, mixing and blending operations, pneumatic or mechanical conveyance, impacts in transfer chutes and at the receiving conveyor, transfers between conveyors or other equipment, and so on.

Dust-collection pickups should generally be located nearby these dust-generating operations whenever dust capture and collection are required. However, one important (but often overlooked) point is that not all dust generation points require dust collection. In fact, there may be situations where dust capture and collection for a given operation could be avoided, and others where dust collection is absolutely required for one reason or another. To determine whether dust capture and collection is actually required at a dust-generation point, consider the following questions:

a. Would even minor fugitive dust releases or leaks potentially create a highly hazardous condition (for example, if the dust itself has significant combustibility or toxicity hazards, or if the presence of the dust in the surrounding area would create a hazard)? Or alternatively, would it be sufficient to mitigate the hazard from fugitive dust using routine housekeeping activities?

FIGURE 3. An operator deals with plugging in a dust-collector hopper

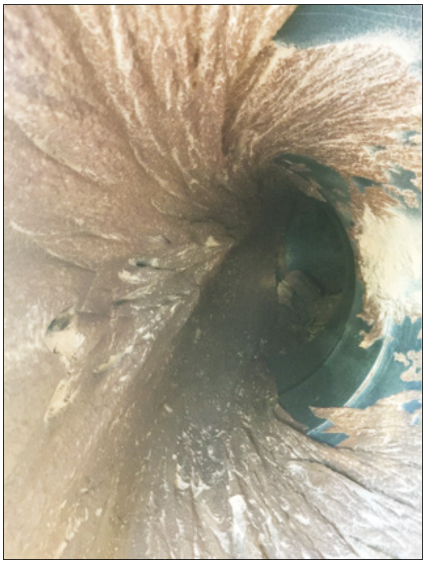


FIGURE 4. Buildup of sticky dust in a 30-in. diameter duct is shown here

b. Is it impossible or impractical to design and maintain the equipment to prevent or minimize dust generation in the first place?

c. If dust generation cannot be prevented and the equipment is not likely to become pressurized, would it be impossible or impractical to design the equipment to keep the dust contained locally?

d. If dust generation cannot be prevented and the equipment may become pressurized, would it be impossible or impractical to keep the dust contained within the equipment using local ventilation (with passive or active vent filters) rather than connecting to a dedicated dust-collection system to remove the dust to another location?

If the answer to the questions above is "no", then the best approach would generally be to not capture and collect the dust at that generation point.

As an example of unnecessary dust collection that illustrates some of the problems it can create, enclosed equipment (such as silos or enclosed conveyors) is often designed with dust collection pickups connected to a dedicated dust-collection system. These pickups were often installed to avoid dust leaks by providing some suction (negative pressure) on the equipment and preventing it from becoming pressurized when air is displaced as the equipment is filled with material. The neg-

FIGURE 5. When solids loading is not taken into account in duct-system design, saltation and buildup can occur

ative pressure may also be in place simply because the equipment has leaky gaskets or covers. These pickups often create significant problems — the ductwork in those particular branches often becomes plugged due to poor duct layout and insufficient velocity (after all, where is the airflow in the branch coming from if the pickup is connected to enclosed equipment?). These duct branches regularly cause issues for the rest of the dust collection system as well.

Figures 2 and 3 show an application that illustrates this, where several silos were filled pneumatically with material by bulk trucks, and pickups for a central dust-collection system had been installed on the silo headspace to try to prevent the silos from becoming pressurized and prevent dust clouds from being released through the pressure-relief valve. The dust collection system plugged extremely frequently (both in the ductwork and at the collector), creating a critical bottleneck in the process that required maintenance shutdowns for cleanout after every single truck unload. These plugging problems not only required operator intervention to resolve, but also made it so that large dust clouds were regularly released from the silo relief valves despite the dust-collection system, since the silos were still becoming pressurized.

The problems were resolved and the process bottleneck removed by keeping the dust contained within the silos, thereby eliminating the need for central dust collection entirely — local vent filters with cartridge filters were installed on the headspace of each silo, with small fans to provide slight active suction to avoid pressurization of the silo headspace during filling.

Consider solids loading

Dust collection systems are often designed based on standard HVAC (heating, ventilation and air conditioning) system principles, calculations and design procedures, such as those given in Refs. 2 and 3. These references also provide some helpful guidance on typical ranges of duct velocities and dust-capture velocities that may be used for various applications. The actual design parameters required to ensure the performance of a given dust-collection system will obviously depend on the specific application, operations and material properties.

Unfortunately, these HVAC-system design guides are for ventilation with air only, and do not account for dust loading in the ductwork. HVAC system design calculations for determining velocities and line resistances (static pressure; SP) may be essentially valid in systems with extremely lean dust loading. However, dust can frequently build up and plug in the ductwork in many applications, even if the velocities are nominally high enough to capture the dust and transport it through the ductwork, if the solids loading is not properly considered during design. Duct plugging occurs particularly often with moist, cohesive or sticky dusts (Figure 4), or if there is (or may be) condensation in the duct. Plugging also occurs if the duct velocity is no longer high enough due to increased system SP or the ductwork is poorly laid-out and saltation occurs (Figure 5).

If dust saltation or buildup does start to occur, it often tends to lead to a chain reaction that ends in plugging — the saltation or buildup reduces the effective duct diameter, increasing line resistance and system SP, which in turn reduces the airflow the fan can provide (potentially by 30% or more), causing the duct velocity to decrease, likely leading to more saltation and buildup, and eventually leading to duct plugging.

Furthermore, it is often important for the dust-collection-system design calculations to account for the solids loading in the ductwork, and include additional line resistance required to accelerate and transport solids through the system. If these additional losses, or resistances, from solids loading are overlooked in the system design calculations, or if the dust loading in the system is higher than anticipated (for example, due to excessive dust generation or overly-aggressive dust capture at one or more capture points, or due to heavy dust particles), there may be significant problems with the system. As an example, if some of the capture points have much higher dust generation than others, and the increased dust loading in those branches is not properly accounted for in design calculations, the additional resistances due to higher dust loading in those branches may lead to the system's airflows being unbalanced. The additional SP from solids loading may also make it so that the fan is significantly under-designed and unable to provide the necessary airflows and velocities required for adequate dust capture and avoiding plugging in the ductwork.

Capture the dust at each point

The system may not be capturing enough dust at each generation point if there is not adequate airflow to ensure sufficient velocity at the dust-generation point, which depends not just on the fan and system design, but also on the actual design of the capture hood/pickup point and its location relative to the dust-generation point. There are

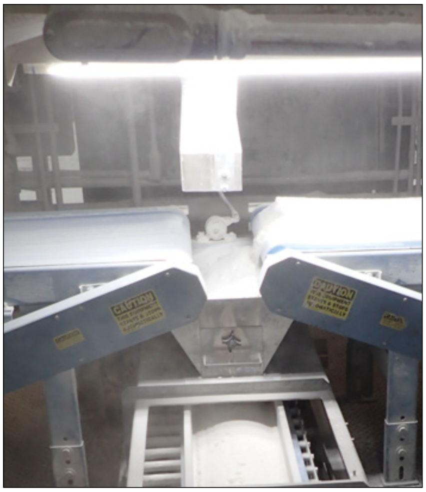


FIGURE 6. This photo shows an example of a dust-capture hood that is located too far from the dust-generation point

a variety of different dust-capture hood design configurations available, depending on the needs of the application. Different hood designs have different relationships between the velocity at the capture hood face (V_{face}) and the actual capture velocity at the dust-generation point ($V_{c,act}$).

As a simple example, if an unflanged, round plain-end pipe is used as a dust pickup, the relationship between V_{face} and $V_{c,act}$ follows the DallaValle equation:

$$(V_{C,ACT} / V_{face}) = A_d / (10x^2 + A_d)$$

where A_d is the area of the pipe face, and x is the distance of the hood face away from the dust-generation point [*1*].

Therefore, if an 8-in.-dia. (A_d = 50 in.^{2}) pickup is located only $x = 4$ in. away from the dust-generation point, the actual velocity at the dust-generation point ($V_{c,act}$) is only about 24% of the velocity at the hood face V_{face}. At $x = 8$ in. away, $V_{c,act}$ is only 7% of V_{face}, and at $x = 12$ in., $V_{c,act}$ drops to only 3% of V_{face}. This means that if the dust-capture hood is located even a seemingly small distance away from the dust-generation point, it loses a significant amount of its ability to capture and collect the dust. As a result, it is critical to locate the capture hood close to the dust-generation point to avoid the rapid loss of air velocity as a function of distance from the hood face, and to factor up the airflow at the hood as required based on velocity loss at distance x. Figure 6 shows an example of a capture hood located too far away from a dust-generation point, leading to significant dust release from even a short free-fall with a fine powder. The dust capture point in Figure 6 is also completely open to the surrounding atmosphere. There should be walls to better enclose the dust-generation point to direct the airflow through the dust cloud and improve the effectiveness of dust capture.

It is also possible that the actual SP for specific duct branches and for the overall system may be higher compared to the design value, potentially due to buildup in the ductwork or to closed (or partially closed) blast gates. The higher SP can also occur if the solids loading in the system was not properly accounted for. Higher SP versus design may be reducing the overall airflow in the system due to limitations of the fan, and potentially throwing off the system SP balancing. This may reduce the airflow and capture velocity in specific branches, and therefore decrease the amount of dust captured at different pickup points.

It is important to not only capture enough dust, but also to avoid capturing too much dust — improperly-designed dust collection systems can often pull excessive material into the ductwork, including "good" product, along with fugitive dust. Not only may this be lost product (and therefore lost revenue), but it also increases the dust loading and resistance/SP in the ductwork, potentially leading to some of the problems discussed previously.

To minimize the risk of bottlenecks due to poor dust-collection system operation, it is critical to consider both your specific application and your material's properties, as measured by proven test methods [*4*]. ■

Edited by Scott Jenkins

Acknowledgements

Figure 1 is reprinted with permission from Ref. 1. All other photos are courtesy of Jenike & Johanson

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Author

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Solids' Characteristics and the Drying Process

Understanding material characteristics is important in designing and defining process criteria for optimal performance of rotary and fluidized-bed dryers

Nick Reckinger
FEECO International

IN BRIEF

ROTARY AND FLUIDIZED-BED DRYERS

MATERIAL CHARACTERISTICS

ESTABLISHING DRYING PARAMETERS

The ability to efficiently, reliably and consistently dry bulk solids in an industrial setting relies largely on tailoring the dryer's design to the unique characteristics of the material to be dried (Figure 1). In other words, material characteristics can have a significant impact on the drying process, with the potential to influence factors such as equipment sizing, configuration, retention time and more. As such, material characteristics must be considered during the early dryer design stages.

This article looks at essential material characteristics to consider when it comes to two common types of industrial dryers: rotary and fluidized-bed dryers.

Rotary and fluidized-bed dryers

In order to understand how material characteristics influence their design, it is first important to understand how each type of dryer works.

Rotary dryers. Rotary dryers work by dropping material through a stream of hot air by tempering combustion gases (Figure 2). Material is passed through a rotating horizontal drum, through which a burner provides drying air either co-currently (parallel flow) or counter-currently to the material. Flights, or material lifters, pick up the material and drop it during rotation, creating a cascade of material in the drum's cross section, which maximizes heat transfer between material and gas. Indirect rotary dryers, which are heated externally and dry material via contact with the heated shell, are also available.

Fluidized-bed dryers. Fluidized-bed dryers work by suspending a bed of material in air via a perforated plate through which combustion gases are passed in an enclosed vessel (Figure 3). This fluidization increases the surface area available to drying by surrounding each and every particle with air. Different fluidization "regimes" or patterns of fluidization can be used to tailor the drying process to the material's specific challenges.

Both dryer types utilize convective heat transfer and rely on how well solids and gas are in direct contact.

FIGURE 1. Bulk solids' characteristics, such as bulk density, heat transfer properties, particle size and more, influence a dryer's efficiency and optimal operating parameters

Material characteristics

A number of different characteristics of the solids to be dried ultimately play a role in dryer design, the most important of which are outlined here. Combined, these characteristics influence dryer design and process criteria such as the following:

- Temperature profiles
- Airflow velocity
- Retention (residence) time
- System pressures
- Unit size
- Percent fill
- Feed and product flowrates
- Rotational speed (rotary dryers only)

It's important to note that in addition to impacting the equipment and process parameters, material characteristics may also, in some cases, influence the choice between which dryer is most appropriate for the application at hand.

Inlet and outlet moisture. The inlet (existing) and outlet (desired) moisture content of the material sets the overall drying objective:

the amount of moisture the dryer will be tasked with removing.

The inlet moisture will also determine whether or not any sort of moisture-reduction pretreatment will be necessary. An additional pretreatment step may also be desirable if the difference between inlet and outlet moisture is considerable. While both rotary and fluidized-bed dryers offer effective moisture removal, removing a substantial amount of moisture in a single unit is often inefficient or impossible.

An especially high moisture content can also affect the flowability of the solids, which in turn influences their behavior in the dryer. A moisture content that promotes a free-flowing consistency is ideal in all settings, no matter the type of dryer.

An appropriate moisture content is critical to the effectiveness of both dryer types, but is particularly important in the fluidized-bed dryer, because of its influence on minimum fluidization velocity. A high-moisture material will require significantly more airflow and energy to fluidize, making the process inefficient.

Rotary dryers are perhaps slightly more tolerant of a high-moisture material, but could still experience challenges that must be designed around, most notably sticking at the inlet.

As a result, whether utilizing a rotary dryer or fluidized-bed dryer, materials with a high moisture content will often require some level of pretreatment prior to the drying unit.

Bulk density. A material's bulk density defines the volumetric capacity of the rotary dryer. In rotary dryers, this expected load helps determine the sizing of mechanical and drive components.

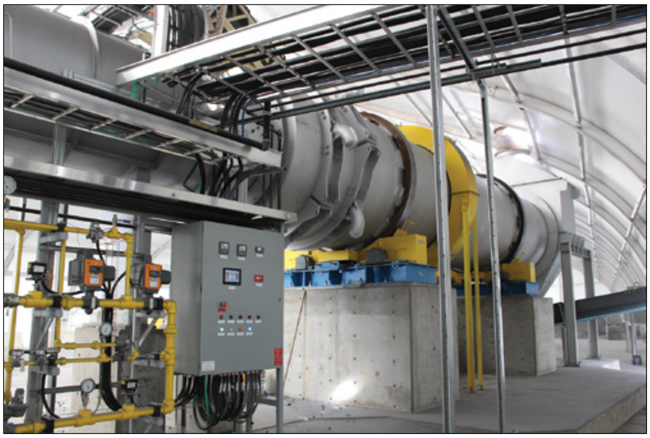

FIGURE 2. Rotary dryers work by dropping material through a stream of hot air in a rotating drum

In a fluidized-bed dryer, as with moisture content, which adds weight, the bulk density will influence the minimum fluidization velocity, or the airflow velocity required to achieve baseline fluidization.

Specific heat. The specific heat (the amount of energy required to raise the temperature of the material) influences how much energy will be required, in this case to bring the material up to the temperature required for moisture removal.

Along with the heat of evaporation for water, this will in turn determine the overall heat input required.

Heat transfer properties. How a material holds its moisture (internally or on the surface) also has ramifications for the dryer design process, again playing into the amount of energy that will be required to reach the target moisture content.

In the case of rotary dryers, heat transfer properties also influence whether the dryer should be designed for co-current or counter-current operation. For example, when a material holds its moisture internally, the counter-current design is beneficial, because it puts the hot material in contact with the hottest gases at its driest state, just prior to discharge, which can help to draw out any remaining moisture.

In contrast, the counter-current design would not be suitable for a heat-sensitive material. Exposing the material to the hottest combustion gases while in its driest state could result in overdrying and product degradation.

Also in the case of rotary dryers, a heat-sensitive material may require the incorporation of a combustion

FIGURE 3. Fluidized-bed dryers work by suspending a bed of material in air via a perforated plate through which hot gases are passed in an enclosed vessel

chamber in order to prevent direct contact between the burner flame and material, thereby reducing potential for product breakdown.

Fragility. A material's propensity for degradation is also important to consider.

In a rotary dryer, a material prone to breakage may require a rolling section without flights at the dryer inlet to give material time to harden before being introduced to the lifting/dropping action imparted by the flights.

In a fluidized-bed dryer, a friable material may require a more gentle fluidization regime in order to minimize breakage that can be caused by particles rubbing against each other while suspended.

Particle size and shape. Particle size distribution and shape are also important characteristics to consider in designing a drying process.

Depending on a material's bulk density and moisture content, particle size typically becomes an issue once it exceeds around 0.5–1 inch in fluidized-bed dryers, due to the energy required to fluidize the material.

In a rotary dryer, particle size has an impact on the airflow velocity, which in turn has ramifications on drum diameter.

Larger particles also generally require a longer retention time to remove the desired amount of moisture, though how the material holds its moisture also plays into this.

Irregularly shaped particles are also harder to dry than uniform ones. With both dryer types, this could mean pretreatment to reduce the particle size distribution (PSD) or make the particle shape more uniform. Fibrous materials can also present problems, "netting" smaller particles together into a larger mass.

Abrasion and corrosion. Materials with abrasive or corrosive qualities must be considered in terms of materials of construction for both dryer types. Further, since the rotary dryer shell is consistently in contact with the material in motion, shell thickness may also be used as a tool to deter wear.

When the material is corrosive, dryer manufacturers should minimize potential points of buildup through design and fabrication, as buildup can promote corrosive wear. This might mean grinding welds smooth, changing feed-hopper design or taking other measures.

End use. While not as commonly influential as some other material characteristics, the intended end use of the product can also factor into the drying process.

In the case of rotary dryers, a material's end use may dictate whether the dryer is of the direct or indirect configuration. While most rotary dryers utilize the direct design, in special cases where material must remain sterile or where a fine particle size risks material entrainment in the gas flow, the indirect dryer can offer an effective alternative.

Feedstock uniformity. The importance of feedstock uniformity cannot be stressed enough. Non-uniform feedstock is often the culprit behind unexplained product quality issues, inefficiencies and process upsets.

While rotary dryers are recognized for their tolerance of slight variations in feedstock parameters, it is still true that the more uniform the material going into the dryer, the more uniform the material that will come out.

In fluidized-bed dryers, feedstock uniformity is of the utmost importance. Fluidized-bed dryers are intolerant to even the slightest variation in parameters, resulting in upset. For this reason, operations expecting some level of variation may be better served by a rotary dryer or other drying technology.

Establishing drying parameters

Due to the variation that can exist across materials and even among the same material from different sources, process development testing is often an essential step in developing a successful drying process and de-risking the path to commercial-scale production.

Batch- and pilot-scale testing services give producers the opportunity to gain a familiarity with their unique source of material and how it responds to the drying process.

Producers can evaluate the characteristics listed above (among others) alongside various process conditions and equipment configurations in order to achieve the most efficient design possible.

These types of services can also be used to troubleshoot or optimize an existing process, a trend becoming increasingly common as producers look to mitigate even the smallest inefficiencies.

Influencing factors such as airflow velocity, dryer size, percent fill, and more, material characteristics form the foundation of the bulk-solids drying process, in the case of both fluidized-bed and rotary dryers. Ensuring a system is designed with characteristics, such as bulk density, heat transfer, particle size and more in mind, will help to achieve a system optimized for efficiency and longevity. As such, process development testing is often an essential step in developing or optimizing a commercial-scale drying system. ■

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Benefiting from Nozzle Flexibility in Piping Design

The inclusion of nozzle flexibility (directional spring rate) in pipe-stress analysis results in more realistic piping reactions on pressure-vessel nozzles, whereby it will be easier to meet the limited nozzle-load capacity of the nozzles. It will surely contribute to a cost-effective design that ensures structural integrity demands

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Piping systems are characteristic of every process plant. Piping systems connect various process equipment items, such as pressure vessels, pumps, compressors, turbines, heat exchangers and so on. It is common practice that a formal pipe-stress analysis is performed for critical piping systems. The pipe-stress analysis performed should comply with the required design code or standard. This analysis not only requires assessing the stresses in the piping system against the allowable stresses, but also assessing the piping reactions that the piping system exerts on the connecting equipment. The problem that arises here often focuses on the assessment of the piping reactions, which in many cases should adhere to company specifications. The reason why the piping reactions exceed the permissible values according to the company specification often lies in the fact that the pipe-stress engineer has considered the terminal point to the equipment infinitely rigid rather than as an element with finite flexibility in his or her pipe stress analysis.

The assumption of a rigid connection for most pressure vessels in the low- or moderate-pressure regime is very conservative and will not lead to realistic piping reactions. Hence, the magnitude of the nozzle loads from the piping-system stress analysis may be overly conservative, depending on the boundary conditions used in the analysis of the piping system.

While a pressure vessel can be considered relatively stiff, it is not infinitely rigid at the nozzles. Completely constraining the model of the piping system where it connects to the pressure vessel will result in external nozzle loads that may be an order-of-magnitude higher than reality. The solution can be found by inclusion of nozzle flexibility into the pipe-stress analysis. The pressure-vessel engineer can provide values for the stiffness of the pressure vessel at the nozzles locations for the piping stress analyst to use. This inclusion will produce more accurate loads at the nozzles. Most systems would have the piping forces and moments increased by two or three times when the connections are considered rigid, as compared with that calculated with flexible connections.

Among the six degrees of freedom at a vessel connection, the flexibilities in the directions of the two bending moments (M_x and M_z) and

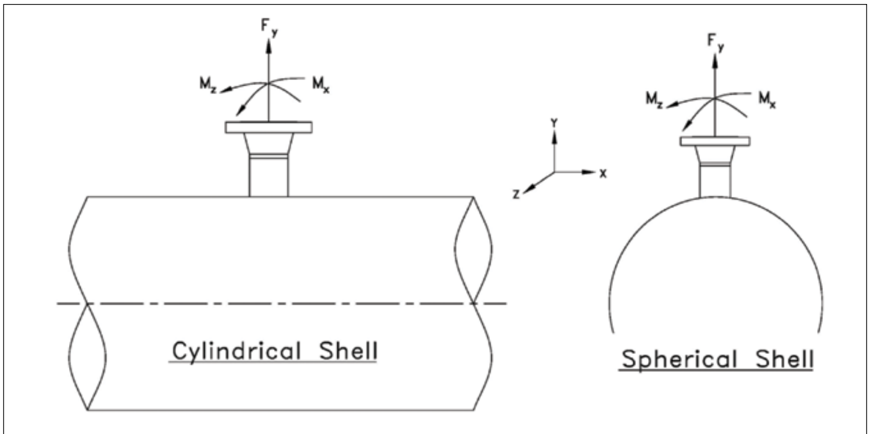

FIGURE 1. Shown here are the directions with significant nozzle flexibilities

TABLE 1. VESSEL DATA OF PAD REINFORCED NOZZLE IN CYLINDRICAL SHELL			
HORIZONTAL VESSEL & FLUSH NOZZLE DATA			
Design pressure: 1.9 MPa (19 bars)	Design temperature: 200°C	Corrosion allowance: 0 mm	Pressure Class: 300 Rated pressure: 4.38 MPa (43.8 bars)
Outside diameter cylindrical shell: 2,000 mm	Wall thickness shell: 20 mm	Nozzle size: NPS 6 in. (NB 500) Outside nozzle diameter: 508 mm	Nozzle thickness: 12.7 mm (nominal): 11.11 mm net
Width of repad: 180 mm	Thickness of repad: 20 mm	Nozzle stand-out: 250 mm	Length of cylindrical shell: 3,556 mm
Nozzle location: midway shell	Shell and repad material: A 515 Gr. 60	Nozzle material: A 106 Gr. B	Flange material: A 105

TABLE 2. RESULTS OF STIFFNESSES AS PER NUMERICAL ANALYSES			
Source	**NozzlePRO**	**FE/Pipe**	**PV Elite**
Axial stiffness (F_Y), N/mm	258,639	256,172	256,861
Inplane rotational stiffness (M_Z), Nmm/deg	681,249,216	678,000,000	677,132,608
Outplane rotational stiffness (M_X), Nmm/deg	221,089,008	220,000,000	219,810,432
Torsional rotational stiffness (M_Y), Nmm/deg	14,649,185,280	13,200,000,000	13,951,570,944

TABLE 3. RESULTS OF STIFFNESSES AS PER ANALYTICAL METHODS		
Source	**WRC 297**	**PD 5500 Annex G**
Axial stiffness (F_Y), N/mm	2,135,594	Rigid
Inplane rotational stiffness (M_Z), Nmm/deg	14,014,902,000	Rigid
Outplane rotational stiffness (M_X), Nmm/deg	232,960,000	Rigid
Torsional rotational stiffness (M_Y), Nmm/deg	Not applicable	Not applicable

TABLE 4. OVERVIEW OF PIPING REACTIONS FOR SITUATIONS #1AND #2							
SITUATION #1							
Node	**Load Case**	**F_X, N**	**F_Y, N**	**F_Z, N**	**M_X, Nm**	**M_Y, Nm**	**M_Z, Nm**
1/Vert.Noz							
	1 (OPE)	157	–476	–427	–883	833	70
	2 (SUS)	148	–1164	–17	34	275	–870
	3 (EXP)	8	708	–410	–917	558	940
	MAX	157/L1	–1,164/L2	–427/L1	–917/L3	833/L1	940/L3
SITUATION #1							
Node	**Load Case**	**F_X, N**	**F_Y, N**	**F_Z, N**	**M_X, Nm**	**M_Y, Nm**	**M_Z, Nm**
2/Horiz.Noz							
	1 (OPE)	–157	–3124	427	696	-459	–4,308
	2 (SUS)	–146	–2417	17	–2	131	–3,308
	3 (EXP)	–8	–708	410	698	–590	–1,000
	MAX	–157/L1	–3124/L1	427/L1	698/L3	-590/L3	–4,308/L1
SITUATION #2							
Node	**Load Case**	**F_X, N**	**F_Y, N**	**F_Z, N**	**M_X, Nm**	**M_Y, Nm**	**M_Z, Nm**
1/Vert.Noz							
	1 (OPE)	556	–1,105	–221	80	1,276	–851
	2 (SUS)	478	–1,553	99	547	751	–1,368
	3 (EXP)	78	448	–320	–467	525	517
	MAX	556/L1	–1,553/L2	–320/L3	547/L2	1,276/L1	–1,368/L2
SITUATION #2							
Node	**Load Case**	**F_X, N**	**F_Y, N**	**F_Z, N**	**M_X, Nm**	**M_Y, Nm**	**M_Z, Nm**
2/Horiz.Noz							
	1 (OPE)	–556	–2,495	221	595	224	–1,619
	2 (SUS)	–478	–2,048	–99	10	575	–1,373
	3 (EXP)	–78	–448	320	585	–352	–247
	MAX	–556/L1	–2,495/L1	320/L3	595/L1	575/L2	–1,619/L1

the direct axial force (F_y) are considered significant (Figure 1). Flexibilities of torsion and direct shear directions are generally ignored and considered rigid.

Vessel-piping interface flexibility

As mentioned before, equipment nozzles are normally modeled as rigid piping junctions, which result in nozzle loads that do not adequately reflect the ability of the nozzle to rotate and displace. To better define the loading on the equipment nozzles it becomes apparent that the nozzle stiffness would need to be included in the piping flexibility analysis.

The stiffness of the nozzle heavily influences the stresses in the piping system and also the forces and moments acting on the nozzle itself. Defining the nozzle as a fixed endpoint for the piping can be unnecessarily conservative or can also render non-conservative results for piping stresses.

The nozzle stiffness and stress results using different calculation methods, such as WRC-297 [*1*], PD 5500 Annex G [*2*], and finite element analysis (FEA), are quite diverse. The analysis results for FEA gives the most reliable and realistic results compared to the other methods. However, FEA can increase the time and cost parameters associated with the normal design process. However, due to mostly psychological concerns, the inclusion of vessel flexibility in the piping analysis is still not universal. Some vessel engineers worry that the inclusion of shell flexibility will ultimately result in a stiffer piping system that might cause damage to the vessel. This is partly true, but it mostly has an adverse effect on the quality of the plant.

Procedures for calculating stiffness coefficients, taken from Refs. 1 and 2, are described in Refs. 3 and 4.

Nozzle flexibilities

Consider an example of a vessel with a pad-reinforced nozzle in the cylindrical shell. The data for such a vessel are presented in Table 1. The nozzle flexibilities for the pressure vessel according to Table 1 are shown in Table 2.

Table 2 shows that the nozzle flexibilities calculated with different software programs are almost the same. All of these software programs are based on numerical FEA. Furthermore, the nozzle flexibilities have also been calculated in accordance with WRC 297 and PD 5500 Annex G, as included in the pipe stress analysis software package CAESAR II. The results of this exercise are shown in Table 3. Note that, for both methods, *extrapolation* of

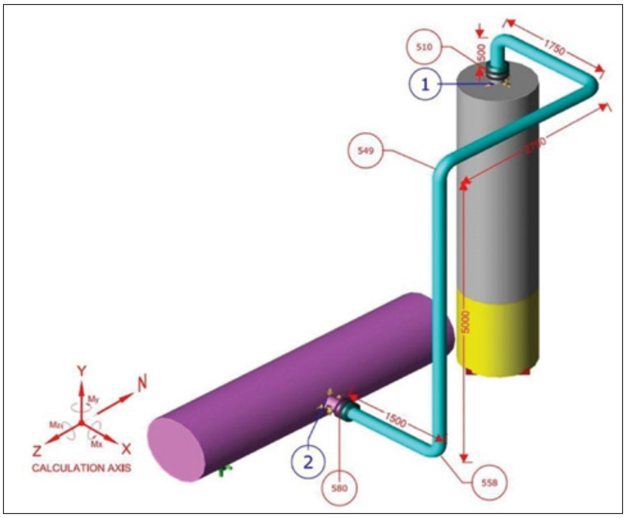

FIGURE 2. This diagram shows the vessel-piping configuration for the example discussed in the text

the curves is required. However, extrapolation will lead to a stiffer intersection.

The nozzle flexibilities computed with NozzlePRO, FE/Pipe and PV Elite differ significantly from those computed with CAESAR II according to WRC 297 and PD 5500 Annex G.

We demonstrate the effect of nozzle flexibility using a piping configuration in which the piping connects to a nozzle in the middle of a curved head of a vertical pressure vessel on the one hand and to the cylindrical shell of a horizontal pressure vessel on the other. It is important to mention that the configuration is not aimed at a stress-wise optimal result, but is randomly chosen to show the effects of nozzle flexibility.

An example

For the configuration shown in Figure 2, the piping reactions were determined with the CAESAR II Pipe Stress Program. This concerns an NPS 6-in. (NB 150) schedule 40 pipe with Class 150 connection flanges on the vessels. Both pressure vessels have an outside diameter of 1,000 mm and a wall thickness of 10 mm. The system is designed for an internal pressure of 7 bars (0.7 MPa) and a temperature of 350°C. Nozzle 1 (top nozzle) is located in the middle of the top head of the vertical vessel and Nozzle 2 (lowest nozzle) is located in the middle of the cylindrical shell of the horizontal vessel with a length of 4,000 mm between the tangent lines. The horizontal shell rests on two saddles of which the right saddle is a fixed point and the left saddle is a sliding point. The distance between the symmetrically placed saddles is 3,000 mm. The vertical pressure vessel is supported by a skirt and attached to a concrete foundation by means of anchor bolts. The contents of the pipe system contain a gaseous mixture with a fluid density of 0 kg/m^3. Insulation of the piping has been omitted. Two situations have been analyzed:

Situation #1. Without taking the nozzle flexibility into account for the two nozzle connections, which means that the connection points are assumed to be completely rigid.

TABLE 5. OVERVIEW DIRECTIONAL SPRING RATE (NOZZLE FLEXIBILITY)		
Nozzle 1 on top of head		
Method	**Calculated with FE/Pipe finite element method (FEM)**	**Ref. 3 (Flexible nozzle neck approach) calculated manually**
Axial translational stiffness, N/mm	161,250	145,588
Rotational bending stiffness, Nm/deg	18,195	25,000
Nozzle 2 on cylindrical shell		
Method		**FE/Pipe (FEM)**
Axial transitional stiffness, N/mm		36,556
Longitudinal bending stiffness, Nm/deg		18,999
Circumferential bending stiffness, Nm/deg		6,301

Situation #2. The nozzle flexibility in the CAESAR II run has been taken into account for both Nozzle 1 and Nozzle 2. Flexibility of both nozzles have been computed with the numerical FE/Pipe software package. The results of the CAESAR II pipe stress analysis are shown in Table 4.

Results of piping reactions

To summarize, the following situations are distinguished:

Situation #1. Nozzle 1 and Nozzle 2 without nozzle flexibility (rigid)
Situation #2. Nozzle 1 and Nozzle 2 both with nozzle flexibility
Note that nozzle flexibility is synonymous with directional spring rate.

The following is extracted from the CAESAR II Pipe Stress Analysis Software:

Load case definition key
Case 1 (OPE): $W + T1 + P1$
Case 2 (SUS): $W + P1$
Case 3 (EXP): $L3 = L1 - L2$
Where:
OPE = operating load case
SUS = sustained load case
EXP = expansion load case
W = Dead weight (pipe weight, insulation weight, refractory weight, cladding weight, fluid weight, rigid weight
T1 = Thermal Set 1 (Temperature #1)
P1 = Pressure set 1 (Pressure #1)
L3 = L1– L2 (a combination case that combines the displacements, forces, and stresses)

Table 4 gives an overview of the results of the calculations for the piping reactions for Situations #1 and #2. It should be noted that the shear forces are normally left out of consideration, since they have a minor effect on the stress levels in the vicinity of the nozzle intersection.

Table 5 gives a summary of directional spring rate (nozzle flexibility) for Nozzle 1 on top of the head, and for Nozzle 2 on the cylindrical shell.

TABLE 6. OVERVIEW OF PIPING REACTIONS & LOAD RATIOS FOR SITUATIONS #1 AND #2									
SITUATION #1 (RIGID NOZZLE)									
Node	**Load Case**	Φ_P	Φ_B	Φ_I	$F=F_Y$, N	$M=(M_X^2+M_Z^2)^{0.5}$, Nm	M_x, Nm	$M_T=M_y$, Nm	M_Z, Nm
Nozzle 1 on top of head	1 (OPE)	0.3730	0.2075	0.5829	–476	886	–883	833	70
	2 (SUS)	0.3730	0.2040	0.5800	–1,164	871	34	275	–870
	3 (EXP)	0.3730	0.3075	0.6793	708	1,313	–917	558	940
SITUATION #1 (RIGID NOZZLE)									
Node	**Load Case**	Φ_P	Φ_B	Φ_I		$F=F_X$, N	$M_T=M_X$, Nm	$M_L=M_y$, Nm	$M_C=M_Z$, Nm
Nozzle 2 on shell	1 (OPE)	0.4849	1.9843	2.0332		–157	696	–459	–4,308
	2 (SUS)	0.4849	1.5221	1.5850		–146	–2	131	–3,308
	3 (EXP)	0.4849	0.4760	0.6496		–8	698	–590	–1,000
SITUATION #2 (FLEXIBLE NOZZLE)									
Node	**Load Case**	Φ_P	Φ_B	Φ_I	$F=F_Y$, N	$M=(M_X^2+M_Z^2)^{0.5}$, Nm	M_x, Nm	$M_T=M_y$, Nm	M_Z, Nm
Nozzle 1 on top of head	1 (OPE)	0.3730	0.2003	0.5788	–1,105	855	80	1,276	–851
	2 (SUS)	0.3730	0.3450	0.7226	–1,553	1,473	547	751	–1,368
	3 (EXP)	0.3730	0.1633	0.5357	448	697	–467	525	517
SITUATION #2 (FLEXIBLE NOZZLE)									
Node	**Load Case**	Φ_P	Φ_B	Φ_I		$F=F_X$, N	$M_T=M_X$, Nm	$M_L=M_y$, Nm	$M_C=M_Z$, Nm
Nozzle 2 on shell	1 (OPE)	0.4849	0.7463	0.8696		–556	595	224	–1,619
	2 (SUS)	0.4849	0.6428	0.7818		–478	10	575	–1,373
	3 (EXP)	0.4849	0.1350	0.4624		–78	585	–352	–247

TABLE 7. INFLUENCE OF NOZZLE FLEXIBILITY ON NATURAL FREQUENCY	
Lowest model natural frequencies computed by CAESAR II	
Situation #1	Situation #2
5.385 Hz (first mode)	4.299 Hz (first mode)
11.783 Hz (2nd mode)	7.283 Hz (2nd mode)
15.612 Hz (3rd mode)	10.203 Hz (3rd mode)

Assessment interface between vessel and piping

As another exercise, we perform the nozzle-load analysis for the same two situations as above according to EN 13445-3, using VES - Software. The software combines the effects of simultaneously acting pressure, axial load and bending moment where the following conditions must be met:

$|\Phi_P| \leq 1.0$ (Individual load ratio)
$|\Phi_B| \leq 1.0$ (Individual load ratio)
$|\Phi_I| \leq 1.0$ (Load interaction ratio)

Note that the load ratios for shear loads have been ignored because the effect is negligible.

The results of the calculations are presented in Table 6.

The load ratios marked in red exceed the permitted unity ratios (1.0) according to EN 13445-3 [*5*]. This means that the nozzle load calculated with CAESAR II for the nozzle on the horizontal pressure vessel is too high.

It turns out that if we perform a calculation in accordance with both WRC 107 [*6*] and WRC 297 [*1*] to evaluate the stresses for Nozzle 2, assuming that the intersection of the nozzles is completely rigid, then the nozzle loads are even not permissible. However, when the flexibility of the nozzle is taken into account, it appears that for Nozzle 2 the nozzle loads according to EN 13445-3 are amply permissible. This also applies if the nozzle loads are evaluated according to WRC 297 and FE/Pipe (FEA). We can therefore conclude that the results where the nozzle is considered flexible are more favorable in terms of nozzle loading. An evaluation of the flange loads according to different methods resulted in overloaded flanges class 150 for both situations, which means that a higher flange class (class 300) must be chosen.

Evaluation methodologies

It should be recognized that the main purpose of piping-stress analysis is to ensure the structural integrity of the piping and to maintain the operability of the system. The latter function is mainly to ensure that the piping forces and moments applied to connecting equipment are not excessive. Excessive piping loads may hinder the proper functionality of the equipment. The function of maintaining system operability requires the investigation of the interface effects with connecting equipment. It is therefore quite crucial to evaluate the acceptability of the loads exerted

by the piping on the nozzle flanges and the local stresses in the vicinity of the nozzle-vessel intersection. The detailed evaluations are as follows, using the nomenclature defined here:

Nomenclature:

D_{BC} = bolt circle diameter
F = axial tensile force on flange
F_M = moment factor (according Table UG-44-1)
G = diameter of effective gasket reaction
K_V = "Koves" factor (according paragraph 2 of D 0701) is moment correction factor
M = bending moment on flange
P_D = design pressure
P_{eq} = equivalent pressure (for checking against flange rating)
P_R = pressure rating = 0.84 MPa

The following applies to Nozzle 1 on top head of Figure 2:

$F = F_Y$
$M = (M_X^2 + M_Z^2)^{1/2}$
$M_T = M_Y$ (torsional moment)

The following applies to Nozzle 2 on cylindrical shell of Figure 2:

$F = F_X$
$M_T = M_X$
$M_L = M_Y$ (longitudinal moment)
$M_C = M_Z$ (circumferential moment)

The following are flange rating evaluation methods for flanges conforming to ASME B16.5 and ASME B16.47 subjected to external loads, using data from Table 5.

To evaluate the maximum flange load for Nozzle 2 on the cylindrical shell Situation #1 (rigid nozzle),

$M = (M_C^2 + M_L^2)^{1/2} = (4{,}308^2 + 459^2)^{1/2} =$
4,332.383 Nm = 4,332,383 Nmm

F is a compressive force, so can be entered at a value of 0 N.

Equation (1) is the Kellogg method for determining the equivalent pressure:

$$P_{eq} = \frac{16M}{\pi G^3} + \frac{4F}{\pi G^2} + P_D \leq P_R \quad (1)$$

Using the value for M determined above, Equation (1) gives:

$P_{eq} = 16 \times 4{,}332{,}383/\pi 194.6^3 + 0 + 0.7 = 3.694$ MPa

This is much greater than the pressure rating of 0.84 MPa.

Equation (2) is evaluation of P_{eq} according to Paragraph 4.3 Chapter D 0701 (Rules for pressure vessels):

$$P_{eq} = \frac{16M}{\pi G^2 D_{BC} K_V} + \frac{4F}{\pi G^2} + P_D \leq P_R \quad (2)$$

Using the value for M determined above, Equation (2) gives:

$P_{eq} = 16 \times 4{,}332{,}383/(\pi 194.6^2 \times 241.3 \times 2.7) + 0 + 0.7 = 1.5943$ MPa

This is also greater than the pressure rating of 0.84 MPa.

Another method for determining P_{eq} *is* the UG-44 ASME VIII-1 method, given by Equation (3):

$$P_{eq} = \frac{16M}{\pi G^3} + \frac{4F}{\pi G^2} + P_D < (1 + F_M)P_R \quad (3)$$

Using the value for M determined above, the left side of the inequality of Equation (3) gives:
$P_{eq} = 16 \times 4{,}332{,}383/(\pi 194.6^3) + 0 + 0.7 = 3.694$ MPa, which is greater that the expression on the right of the inequality:
$(1 + 1.2)0.84 = 1.848$ MPa.
In fact, it is important to note that *none* of the conditions are met for the most heavily loaded nozzle flange (Nozzle 2, Situation #1)! However, when we enter the bending moment that applies to Situation #2, it appears that the flange load according to UG-44 can be tolerated for the class 150 flange, because Equation (1) in this case is:
$M = (M_X^2 + M_Z^2)^{1/2} = (1{,}619^2 + 224^2)^{1/2} =$
1,634.423 Nm = 1,634,423 Nmm
In this case, the left side of the inequality of Equation (3) gives:
$P_{eq} = 16 \times 1{,}634{,}423/(\pi 194.6^3) + 0 + 0.7 = 1.8296$ MPa
which is less than the right side of the inequality of Equation (3),
$(1 + 1.2)0.84 = 1.848$ MPa.

Comment

If the evaluation according to the above methodologies fails, there is an option to evaluate the flange connection according to ASME BPVC Section VIII - Division 1; Appendix 2 [*7*] in which the external loads are converted into an equivalent pressure and added to the design pressure that must be successively entered in the flange calculation. For the relevant NPS 6-in. Class 150 flange, this means that the flange complies. Such a check was also carried out in accordance with EN 13445-3; clause 11 and it was found that the flange rating was satisfactory.

Natural frequency

Natural frequency and mode shapes are dynamic properties of the structure. They are controlled by the mass and stiffness of the system. The natural frequency and mode shapes describe the tendency of the structure to vibrate when subjected to dynamic loading. Natural frequencies and mode shapes of a structure are determined by modal analysis. They are computed starting from the mode with the lowest frequency. The lowest natural frequency is called the fundamental natural frequency. Since only the modes with lower frequencies get a significant response to the source of excitation, only modes with lower frequencies are calculated for the analysis. Assigning nozzle flexibility influences the dynamic behavior of the pipework. For the system in question, the differences in natural frequencies are relatively small (Table 7). If the nozzle flexibility is taken into account, this leads to a lower natural frequency of the pipework, which

can be seen as a general trend in piping systems. Furthermore, the magnitude of the system stresses and the stress distribution are influenced by considering the flexibility of the nozzle. The intensity of the system stresses decreases if the nozzle flexibility is taken into account in the pipe stress analysis.

Concluding remarks

From this study, it can be concluded that for relatively thin pressure vessels, it is very attractive to take the nozzle flexibility into account in the pipe-stress analysis. This not only results in more realistic nozzle loads compared to when the piping-vessel interface is considered completely rigid, but can also lead to advantages for the piping layout (narrower footprint). In addition, you prevent the pressure-vessel nozzle from requiring additional reinforcement on top of that required for internal pressure. Another advantage is that in many cases a higher flange rating of the connecting flange with the equipment in particular can be avoided. Anyway, inclusion of the nozzle flexibility shows a decreasing trend in the magnitude of nozzle loads. Overall, it is plausible that incorporating nozzle flexibility into the pipe-stress analysis provides benefits with respect to lower exerted loads on pressure-vessel nozzles, more realistic system stresses and stress distribution without compromising the structural integrity. ■

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Chemical Recycling: A Deep Dive on Depolymerization

Looking at the challenges and benefits of various recycling technologies, this article uses polymethyl methacrylate (PMMA) as an example to analyze the economics and design considerations for depolymerization processes

Jean-Luc Dubois
Trinseo PLC

Plastics are a valuable commodity in society and provide versatile materials for a variety of industries. Millions of tons of plastic are produced worldwide each year for applications in many industries, including building and construction, packaging, automotive, consumer electronics and healthcare.

However, as plastics have become more versatile, there are growing challenges related to several aspects of plastic production and use, including the impact of greenhouse gas (GHG) emissions from production and disposal, and the effect of landfilling, incineration and littering on the environment. Waste and disposal have become such a leading concern worldwide that regulators and industry organizations are now focused on developing a more circular economy. This can be seen in the European Green Deal and forthcoming end-of-life vehicle (ELV) directive, as well as others in North America and Asia. Many of these regulations focus on how waste-plastic materials can be reintegrated back into the value stream to reduce (and perhaps one day eliminate) dependency on virgin, fossil-based raw materials. The industry's first look at the ELV directive last year is a prime example, as it could mandate automakers to use 25% recycled plastics, a quarter of which must come from ELVs.

Circularity has significant buy-in from industry organizations that are delivering strategies to align chemical manufacturing with these forthcoming regulations, such as Plastics Europe's roadmap released in 2023. The first strategic pillar of this roadmap is to make plastics circular, which it considers one of the "fastest, most affordable, effective and reliable methods for reducing GHG emissions from the plastics system [*1*]."

However, to develop a circular economy, the chemical process industries (CPI) must first reduce their dependence on virgin, fossil-based raw feedstocks through recycling technologies that recover high-quality and high-purity materials that can be integrated into the manufacturing process. It is instrumental that these economies incorporate recyclers that can collect, sort and process waste streams to generate recycled feedstocks for use in demanding applications.

While mechanical recycling has been the hallmark recycling method for decades, the time has come for investment in new technologies that enable more product design flexibility and meet performance standards. Chemical and physical recycling technologies are catalysts for change and must be incorporated as part of the CPI's investment in a circular-economy infrastructure. Recycling technologies and processes must complement one another to facilitate a vibrant plastics economy that is not dependent on virgin raw materials.

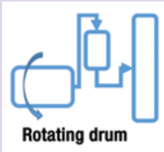
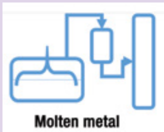
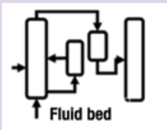
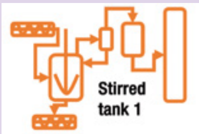
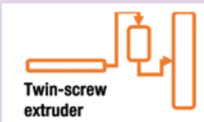
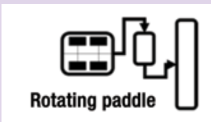
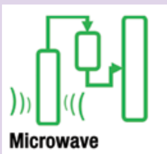
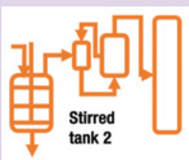
FIGURE 1. A European chemical manufacturing facility that includes a PMMA depolymerization plant is shown here

Types of recycling processes

All recycling technologies fall into three main categories: mechanical, physical or chemical. These technologies can be used on many plastic materials to yield different results or to complement each other, depending on the final products.

Mechanical recycling has been the preferred recycling method to date [*2*]. It requires waste materi-

TABLE 1. OVERVIEW OF DEPOLYMERIZATION TECHNOLOGIES

Advantages	Technology	Disadvantages
• Inexpensive technology • Established track record	 Dry distillation	• Batch operation means frequent heating and cooling cycles • Short equipment life • Solid residue accumulation • Scaleup limitations • Large amount of polymer immobilized in the unit (potential safety issue)
• Inexpensive technology • Unloading of solid residue • Homogeneous mixing	 Rotating drum	• Batch operation means frequent heating and cooling cycles • Short equipment life • Scaleup and safety issues (rotating gaskets, thermal expansion) • Limited productivity
• Continuous process • High rMMA purity • Residence time of only a few minutes • Fast shutdown possible	 Molten metal	• Generates solid residues contaminated with lead (or other metals like tin) • Cannot process scraps that would generate more solid residues
• Continuous process • High heat-transfer rate • Short residence time (of the gas)	 Fluid bed	• High energy consumption • Cannot process scraps that would generate more solid residues • Limited productivity • Expensive technology
• Continuous process • Can be used for a wide diversity of scraps	 Stirred tank 1	• High equipment cost • Difficult agitation of molten polymer
• Continuous process • Recyclers are familiar with the technology • Short residence time and fast shut-down • Renewable electricity as energy source	 Twin-screw extruder	• Capacity may be limited to 5,000 tons per line
• Continuous process	 Rotating paddle	• Scaleup limitations (heat transfer) • Safety concerns
• Input the energy where it is needed • No thermal gradient in the product • Renewable electricity as energy source is possible	 Microwave	• Requires using microwave sensitizer (such as carbon residue, graphite or silicon carbide) • Scaleup limited by the irradiation volume (penetration depth
• Renewable electricity as energy source possible	 Inductive heating	• Requires using a material that absorbs the electromagnetic waves inside the reactor • Scaleup limited by the irradiation volume (penetration depth)
• Continuous process	 Auger-screw	• Not self-cleaning (single screw) • Long residence time
• Continuous process • Low-temperature operation possible • Staged depolymerization • Possible temperature gradient	 Stirred tank 2	• High residence time • Larger volume immobilized in the reactor (safety)

als to be processed, sorted and treated or cleaned before they undergo grinding and compounding, so that the material maintains its chemical structure and original color.

Physical recycling, also known as selective dissolution, is currently gaining interest with several polymers. Like mechanical recycling, it preserves the molecular weight of the polymer. In comparison to mechanical recycling, this process enables a broader acceptance of lower waste quality. Similarly, though, in some cases, the process can yield nearly 100% material recovery.

However, there are some drawbacks to mechanical and physical recycling technologies because they do not return the material to its original monomer. First, the characteristics — such as the polymer chain length — can potentially become degraded over time, as it continues to be recycled. This can affect the mechanical and optical properties over repeated recycling cycles so that its performance is no longer adequate, and the recyclate needs to be downcycled [2].

Second, mechanically recycled materials are typically more likely to contain undesired additives and inhibitors, as well as polymeric impurities, which cannot be removed during the process [2]. Vehicle parts are a prime example of this — the materials are colored and produced with an anticipated lifecycle of at least 10 years. Those older vehicles could contain chemicals

that have since been banned from use or include contaminants that cannot be removed during recycling. With this in mind, materials utilized for automotive applications or other long-life applications can be difficult to recycle via mechanical methods, since color and additives cannot be removed during this process. For colored materials, these wastes are processed for use in all-black and dark applications. Alternatively, those materials that include additives and banned chemicals should not be mechanically recycled and typically end up being incinerated or landfilled.

Third and final, some materials simply cannot be mechanically recycled. An example of this is polymethyl methacrylate (PMMA) cast sheets, since they begin to degrade at the temperatures generated by mechanical recycling due to their unique properties and high molecular weight. By limiting the PMMA waste streams that can effectively be mechanically recycled, a significant PMMA waste portion is landfilled or incinerated.

Chemical recycling, on the other hand, utilizes methods like pyrolysis (heat treatment in the absence of oxygen) and solvolysis (heat treatment in presence of a chemically active agent) to return the polymer to its monomer form. Gasification (heat treatment in the presence of oxygen) generates synthesis gas (syngas), a mix of carbon monoxide and hydrogen, from which multiple products can be made, the most common being methanol, ethanol and ammonia. However, it does not often yield the monomer or one of its building blocks. Research shows, within this family of processes, that depolymerization is the most sustainable option because, by returning the material to monomer form, there is, in theory, no limitation to the recyclability of the solution in a closed-loop system [*2*]. In this context, closed-loop refers to when waste plastic can be used in exactly the same application, whereas in an open-loop system, the waste is recycled into another, less demanding application. Additionally, this enables the recycling of contaminated or difficult waste. To date though, chemical recycling contributes marginally to the total recycled volumes, with less than 3 wt.% of European plastics being recycled undergoing chemical processing [*2*].

When recycling processes are operated with a high mass yield, they keep the carbon in the economy for a longer time, for multiple cycles. For example, a process operating at 90 wt.% mass yield in a closed-loop system will retain 50% of the mass after six recycling operations ($0.9^6 \approx 0.5$). PMMA and polystyrene pyrolysis processes operate at much higher mass yields than mixed polyolefins/plastics pyrolysis and are therefore more appropriate for an extended number of recycling cycles.

A model for depolymerization

End-of-life PMMA is an example of a waste stream that can benefit from the expansion of chemical recycling via depolymerization (Figure 1). PMMA has a forecasted market value of 4 million tons/yr by 2025 and will be worth $6 billion by 2027 [*3*]. Sold under the brand names of Perspex, Plexiglas and Altuglas, PMMA (also known as acrylic) is a transparent thermoplastic that can be used as an alternative to glass because it is resistant to ultraviolet (UV) light, is transparent and has high light transmission. Research shows that each year, 10% of produced acrylic materials end up as post-production collected waste [*3*], but that as much as 90% could be collected as post-consumer waste, so there is significant room for growth in the recycling of this material.

Depolymerization has long been known as a desirable method for recycling PMMA materials. Just 17 years after acrylic was first synthesized, an archaic form of the depolymerization process was patented [*3*]. However, since PMMA and its monomer form — methyl methacrylate (MMA) — represent just a small percentage of the market share for all plastics [*4*], investment into advancing this recycling technology has been limited. That said, PMMA provides opportunities to remove valuable plastics from the waste stream for recycling. The geographic distribution of acrylic recyclers around the world, and their capacity to process the material, shows that worldwide, 100,000 to 150,000 tons of PMMA can be recycled each year across fewer than 75 facilities [*5*]. Additionally, historically in Europe, waste streams have been exported to China for processing that generate low-quality PMMA, but this method cannot persist. Upcoming regulations would limit the ex-

port of many plastics waste streams outside of European borders, so the industry must adapt and find methods for generating usable recyclate that meets global directives. Depolymerization enables manufacturers to achieve realistic recycling goals that can feed a closed-loop system. The latest advancements in PMMA circularity have come from a chemical industry consortium, MMAtwo (www.mmatwo.eu), which was funded by the European Union's Horizon 2020 research and innovation program. This research has been monumental in making depolymerization a more effective recycling process for acrylics that keeps them from being downcycled.

Driving depolymerization

Depolymerization falls under the pyrolysis family of chemical recycling, and from this, there are a variety of methods to produce regenerated MMA (rMMA). The most common method uses high temperatures to generate a liquid monomer. This method generates a vapor of the monomer, which is later condensed. When operating a depolymerization facility, there can be some inherent safety concerns depending on the methodology in place, as follows:

- The recycling technology may operate at a higher temperature than the MMA self-ignition temperature
- The potential formation of solid residues that could be pyrophoric
- The required cleaning operations
- The amount of material that is immobilized within the reactor

Technology evolution

The technology has come a long way since its initial patent, which was for a "heat-transfer bath process [*3*]." While molten-metal baths are still in practice at some depolymerization facilities, there are now many different technologies based on the significant variations that recyclers and chemical manufacturers use to depolymerize acrylic polymers. There are currently 11 technologies that have been developed for the depolymerization of PMMA, which MMAtwo explored at 24 sites around the world to better understand how companies were generating rMMA. The advantages and disadvantages of each technology are illustrated in Table 1. MMAtwo explored these technologies to understand how high-quality rMMA could be generated and remain profitable.

MMAtwo looked at a variety of factors when deciding the advantages and disadvantages of each method, including safety, economic feasibility, scalability, process and more. With some, while there were benefits, environmental, health and safety (EHS) concerns far outweighed these, and for others, the potential of additional steps to remove residue or lingering elements would be cost-prohibitive. The research by the consortium showed that the twin-screw extruder process was the most advantageous. This process, which is a variation of the dry distillation method, utilizes a plug-flow stirred reactor so that the heat transfer can be maximized [*5*].

In this method, liquid rMMA is produced utilizing high electrical heat and a shearing from the mixing screw. During the recycling process, rMMA is captured by the twin-screw extruder, cooled in a heat exchanger, and then purified. MMAtwo found that this method was inherently safer than other methodologies since it was self-cleaning and the reactor had less PMMA holdup at any given time, so the polymer could more readily be removed in the case of an emergency shutdown.

MMAtwo utilized this depolymerization model to develop a new value chain for handling and recovering PMMA waste. While previous models could generate purity levels from 91 to 99 wt.%, the MMAtwo models have consistently generated 99.5 to 99.8 wt.% (and even more, in some cases) [*3*]. By building on an already successful model, the consortium was able to develop rMMA product with high purity that can be used in the same applications as virgin MMA, such as in vehicle taillights or windows that require high optical quality.

Results of the MMAtwo study not only showed that the products were of high quality, but also that they had a reduced environmental impact compared to their virgin counterparts. Most of the facilities that utilized depolymerization technology, and which were evaluated by the consortium, had at least a 70% reduced carbon footprint compared to those facilities producing virgin MMA [*5*]. Additionally, this form of PMMA recycling for rMMA consumed less energy and water than the virgin process that uses acetone as feedstock [*5*]. This could have a significant impact on those companies looking to reduce their environmental impact.

As regulations continue to evolve, and the chemical industry pursues more circular solutions, depolymerization provides a unique opportunity to reuse wastes that would otherwise be incinerated or landfilled. Next-generation depolymerization technologies could completely close the loop by yielding continuous high-quality monomer that has no discernible difference from its virgin counterpart. ■

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Improving PRV Cost of Ownership with Upstream Rupture Discs

The costs associated with installing and maintaining pressure-relief valves (PRVs) can often be reduced by equipping systems with upstream rupture discs

Daniel Willis
Fike Corp.

Reclosing pressure-relief devices, commonly referred to as pressure relief valves (PRVs), are designed to allow for the release of overpressure and to reclose when the pressure returns back to an acceptable level.

PRVs are commonly used throughout facilities in the chemical process industries (CPI) for safety functions, including the following:

- Protect equipment and personnel by safely releasing pressure before equipment rupture or an explosion can occur
- Prolong equipment life and prevent damage to pipes, reactors and storage tanks by keeping pressures at desired design limits
- Ensure the production process runs efficiently and pressure-related downtime is minimized

While pressure relief is a required element of chemical manufacturing, PRVs are not the only device capable of protecting a process from pressure-related hazards.

Rupture discs are non-closing pressure-relief devices that are intended to burst once the intended burst pressure is reached. After activation, the membrane remains open, resulting in a complete discharge of the pressure in the installation.

Both rupture discs and PRVs may be used independently as the primary source of pressure relief. However, using rupture discs in combination with PRVs often offers the most appropriate and most cost-effective solution.

Several arrangements exist in which rupture discs and PRVs may be used in tandem, but perhaps the most common method is installing a rupture disc upstream of a PRV, which offers several significant advantages, which are outlined throughout this article.

Lower-cost PRV materials

Depending on the process media, PRVs are often required to be constructed of certain special — and often expensive — materials to protect against corrosion. These materials are not only necessary for the body of the PRV but also for its internal components, including the spring, poppet, seat, screws, O-rings, gaskets and more.

Therefore, PRVs constructed of such non-standard materials can be extremely expensive and may have long lead times. And if any of the internal components become corroded, costly replacement parts are needed and repair could result in downtime.

This can all be avoided by installing a media-compatible rupture disc upstream of the PRV. Then, the valve is physically isolated from the process and protected from the potentially corrosive media. In other words, the PRV's exposure to the media is limited to an overpressure situation when the rupture disc bursts and opens. In short, this combined assembly allows for the use of PRVs and related spare parts that are constructed of "standard" materials, resulting in a substantial reduction in maintenance and replacement costs.

Allow for in-situ testing

Periodic testing of PRVs is required by industry standards organizations, including the American Society of Mechanical Engineers (ASME; www.asme.org), American Petroleum Institute (API; www.api.org), EN (European Standards) and various other regulating bodies to ensure proper calibration and to meet regional standards.

This process usually requires the uninstallation of each PRV, which depending on the scale of the process, can be a time-consuming and costly endeavor because of the associated downtime. However, using rupture discs upstream of PRVs may allow for testing without the removal of the devices. Below are the required steps to carry out such a testing procedure:

- Pressure is applied in the space via compressed air between the rupture disc and PRV. The pressure is manually or automatically monitored
- The pressure between the rupture disc and PRV rises to the opening pressure of both the rupture disc and PRV. The rupture disc should not be damaged during the test cycle
- As the pressure reaches the opening pressure of the PRV, it will open. The measured opening pressure can now be compared to the rated nominal opening pressure of the PRV to determine if it is functioning within its design parameters — all without removing the PRV

Fike

FIGURE 1. PRVs are essential in protecting against overpressure in CPI plants, but the use of upstream rupture discs can enhance PRV operation while also reducing costs

Prevent leakage and emissions

In order to achieve leak tightness, most spring-operated PRVs rely on special metal-to-metal sealing surfaces, which inevitably results in some leakage that increases as

the operating pressure approaches the valve's set pressure. PRV leakage rates are addressed in industry standards, and acceptable leakage rates are defined in API 576, which covers the inspection of pressure-relieving devices. API 527, the standard covering seal tightness in PRVs, calls for a maximum daily leakage rate of 1.5 std. ft^3 for metal-seated PRVs.

Furthermore, it is common for PRVs to partially open when pressure builds but doesn't quite meet the PRV's set pressure. PRVs may leak or "chatter," resulting in unwanted emissions and lost product.

Where such leak rates are unacceptable for environmental or safety reasons, rupture discs positioned upstream of the PRV eliminate emissions by up to 100 times in a simple and cost-effective manner by providing a leak-tight seal and avoiding PRV chattering and leaking.

Tandem installation design

When installing a rupture disc upstream of a PRV, there are several important considerations that must be understood to ensure proper operation.

According to ASME UG-132(a)(4)(a), the marked burst pressure of the rupture disc should be between 90 and 100% of the marked set pressure of the PRV. However, EN ISO4126-3 paragraph 7.2 says, "*The maximum limit of bursting pressure … shall not exceed 110% of the … set pressure or a gauge pressure of 0.1 bar, whichever is greater …*" and "*The minimum limit…should not be less than 90% of the…set pressure.*" While slightly different, the basic guidance between the two standards is the same. In short, keeping the rupture-disc specified burst pressure and PRV set pressure at the same nominal value, ignoring tolerances, meets the intent of each of the standards and is relatively easy to implement.

It is also critical to note that no fragmentation of the rupture disc is allowed, because loose parts may obstruct the valve orifice or restrict the valve from reclosing. It should also be noted that not all rupture discs are created equal, and many can experience fragmentation. Non-fragmenting discs are engineered with an "opening feature," which may be created by a score line, laser or other means, that guides the rupture disc's petals to open in a pre-determined manner without fragmentation. Without this opening functionality, the metal stretches until the weakest part of the disc can no longer withstand the pressure and breaks into pieces.

Additionally, sufficient distance needs to be available for the rupture disc to open without blocking the PRV nozzle. For example, a single-petal rupture disc may extend beyond the height of the holder and reach into the inlet section of the PRV.

The rupture disc should also be "close-coupled" with the PRV, thereby assuring that the pressure drop during flow at the inlet of the relief valve does not exceed 3%, as required in industry standards. Longer distances between the rupture disc and PRV may result in the creation of reflective pressure waves upon opening of the rupture disc and may result in undesired re-closing of the rupture disc or even fragmentation.

Since the rupture disc, like the PRV, is a device that reacts to differential pressure between the upstream and downstream side, measures need to be taken to avoid that any unnoticed pressure increase occurs in the closed cavity between the rupture disc and PRV inlet. This pressure may increase due to a number of factors, including temperature within or around the process. Any unnoticed pressure changes are commonly identified through the use of a pressure gage or indicator.

Industry code requires that the capacity of the PRV must be derated by 10%, but combination capacity testing will decrease that requirement.

Finally, as one can deduce from the technical nature of these assemblies, extreme care must be taken when selecting the correct rupture disc for the job, and therefore, when selecting the ideal rupture disc manufacturing partner.

A reliable rupture disc is required to ensure it bursts precisely at the intended moment (burst tolerance), that it can handle the full pressure of the system without degrading (operational ratio), and that it can endure the repeating on-and-off nature of the chemical production process (cycle life). ■

Edited by Mary Page Bailey

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Modular Solutions Revolutionize Carbon Capture

MAN Energy Solutions' modularized compression technology optimizes carbon capture, utilization, and storage (CCUS) for diverse industrial applications.

CCUS is pivotal in achieving global climate goals, particularly those set by the 2015 Paris Agreement. As industries strive to reduce carbon emissions, MAN Energy Solutions offers innovative, modularized CCUS solutions that significantly enhance efficiency and cost-effectiveness.

Meeting Market Demand with Modularization

The projected demand for CO_2 compressors is surging as industries seek to mitigate greenhouse gas emissions. MAN Energy Solutions' modularized compression systems cater to this demand by streamlining production, reducing onsite assembly time, and ensuring high-quality outcomes. Modularization allows for the integration of standardized components, leading to economies of scale, faster delivery, and reduced CAPEX and OPEX.

Technological Advantages

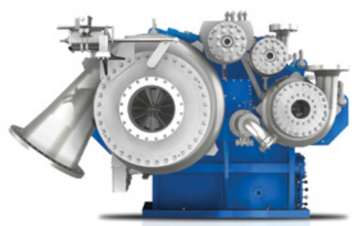
MAN Energy Solutions' integrally geared RG compressors are at the heart of their CCUS offerings. These compressors are engineered to handle both wet and dry CO_2 with water contents above 50%, flows up to 600,000 Nm³/h, and discharge pressures reaching 250 bar. By incorporating these compressors into modular designs, MAN Energy Solutions addresses various transportation and utilization scenarios for captured CO_2.

Economic and Environmental Benefits

Modularized components not only lower production costs but also minimize environmental impact. Standardization reduces waste and optimizes resource use, making the production process more sustainable. Additionally, the ability to preassemble units in a controlled environment enhances quality and accelerates project timelines, making CCUS projects more viable for industries.

Real-World Applications

With over 30 years of experience and a million hours of operation in CO_2 compression, MAN Energy Solutions has a proven track record. Their technology solutions are already making a difference globally, from carbon capture in cement plants to CO_2 utilization in chemical production.



Integrally geared RG compressor by MAN Energy Solutions

Conclusion

As the race to combat climate change intensifies, MAN Energy Solutions' modular CCUS technology offers a practical and efficient path forward. By reducing costs and accelerating deployment, these solutions support industries in their journey towards zero emissions, contributing significantly to global sustainability efforts.

www.man-es.com

Electricity instead of steam for thermal separation

GEA Mechanical Vapor Recompression for new and existing plants

Thermal separation processes, such as evaporation, distillation and crystallization are energy intensive. Efforts to improve their efficiency while reducing their energy consumption, and thus, costs, have been constantly made throughout the course of their usage and further development. First, with single-effect plants heated by live steam, then, with multiple-effect plants; equally steam-powered. Going further, thermal vapor recompression became a staple and now, Mechanical Vapor Recompression (MVR) is turning into the preferred heating source for evaporation, distillation and crystallization plants.

Mechanical Vapor Recompression is an energy-recovery process that allows for residual heat to be continuously recycled. Using MVR results in significant reductions on both energy costs and carbon emissions while efficiency is boosted, reaching higher COP (Coefficient Of Performance) values that directly translate into higher profitability.

Mechanical Vapor Recompression can be used for either compressing water vapor or compressing organic vapor. It is also possible to work with MVR to compress flammable organics - as long as an explosion-proof design of it is in place.

Mechanical Vapor Recompression has been a staple technology at GEA for decades, with unrivalled process expertise backed by thousands of thermal separation plants functioning across industries and applications around the world.

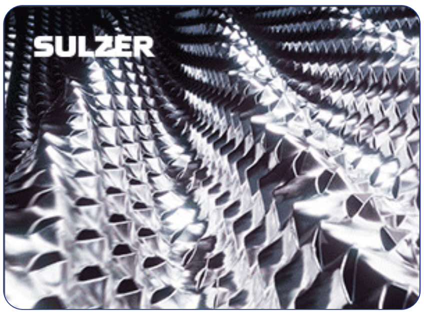
https://go.gea/3ir

Boost distillation efficiency with Sulzer's latest innovation in structured packing technology

Since the Sulzer Mellapak product family launched in 1976, it has become synonymous with structured packing. The newly released MellapakEvo™ technology is the product of Sulzer's extensive research and development efforts, leveraging decades of expertise to push the boundaries of efficiency and performance in distillation processes.

Its highly effective interfacial or wetted area, which enhances mass transfer between the vapor and liquid phases for component separation in a distillation column, defines this new generation of structured packing.

The pressure drop is minimized due to the packing's low gas flow resistance, thereby increasing its useful capacity. The efficiency is significantly influenced by the wettability of the packing surface. A superior texture ensures the creation, maintenance, and continuous renewal of the liquid film on the wetted surface, maximizing the utilization of the packing. The result is an enhanced performance of the distillation column while the useful capacity is extended.



These upgrades collectively result in up to 40% greater efficiency than the MellapakPlus™ 252.Y structured packing, and approximately 20% higher capacity than MellapakPlus™ 452.Y while delivering similar separation efficiency. This makes it ideal for use in diverse applications in the chemical processing industry where its ability to offer both high efficiency and a low-pressure drop is vital.

As the leader in the design and production of packed column technology, Sulzer is dedicated to driving excellence and reducing the environmental impacts of the distillation columns. Together with our crucial MellaTech™ column internals technology and application know-how, Sulzer continues to focus on bringing optimum solutions with greater efficiencies and lower energy consumption to our customers.

Sulzer is poised to lead these advancements and ensure that Mellapak continues to set the standard for structured packing over the next 50 years and beyond.

To learn more about MellapakEvo™ and the rest of Sulzer's structured packing solutions, visit: www.sulzer.com

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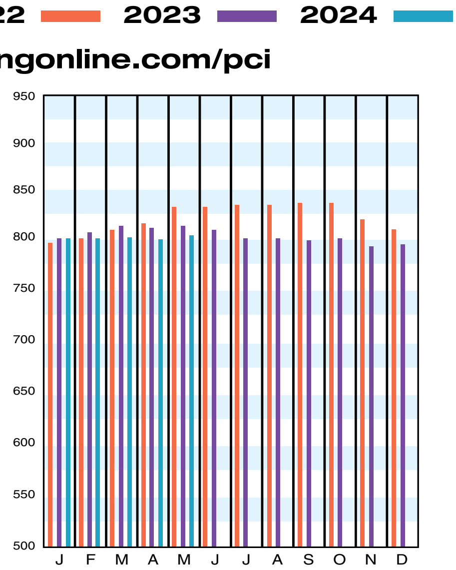
Economic Indicators

Download the CEPCI two weeks sooner at www.chemengonline.com/pci



CHEMICAL ENGINEERING PLANT COST INDEX® (CEPCI)

(1957–59 = 100)	May '24 Prelim.	Apr. '24 Final	May '23 Final
CE Index	800.0	799.5	808.8
Equipment	1,005.3	1,005.0	1,021.3
Heat exchangers & tanks	801.6	805.4	841.6
Process machinery	1,033.0	1,036.5	1,033.8
Pipe, valves & fittings	1,356.2	1,344.7	1,399.8
Process instruments	580.5	575.4	564.5
Pumps & compressors	1,543.4	1,542.9	1,438.3
Electrical equipment	827.7	823.2	796.4
Structural supports & misc.	1,115.9	1,123.1	1,147.6
Construction labor	376.6	374.7	364.6
Buildings	803.8	804.7	818.2
Engineering & supervision	315.7	316.2	314.4

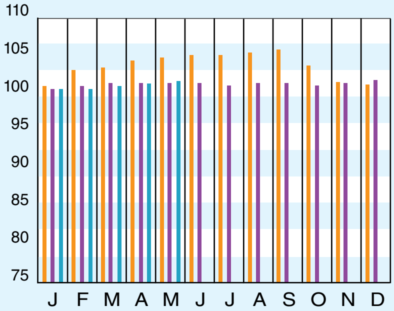
Annual Index:
2016 = 541.7
2017 = 567.5
2018 = 603.1
2019 = 607.5
2020 = 596.2
2021 = 708.8
2022 = 816.0
2023 = 797.9

Starting in April 2007, several data series for labor and compressors were converted to accommodate series IDs discontinued by the U.S. Bureau of Labor Statistics (BLS). Starting in March 2018, the data series for chemical industry special machinery was replaced because the series was discontinued by BLS (see *Chem. Eng.*, April 2018, p. 76–77.)

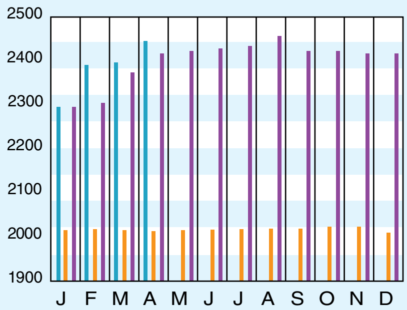
CURRENT BUSINESS INDICATORS

CURRENT BUSINESS INDICATORS	LATEST			PREVIOUS						YEAR AGO		
CPI output index (2017 = 100)	May '24	=	99.7	Apr. '24	=	98.6	Mar. '24	=	99.0	May '23	=	99.7
CPI value of output, $ billions	Apr. '24	=	2,473.6	Mar. '24	=	2,445.6	Feb. '24	=	2,423.5	Apr. '23	=	2,354.9
CPI operating rate, %	May '24	=	78.5	Apr. '24	=	77.7	Mar. '24	=	78.2	May '23	=	79.5
Producer prices, industrial chemicals (1982 = 100)	May '24	=	301.2	Apr. '24	=	303.5	Mar. '24	=	297.8	May '23	=	323.3
Industrial Production in Manufacturing (2017 =100)*	May '24	=	99.8	Apr. '24	=	99.0	Mar. '24	=	99.4	May '23	=	99.8
Hourly earnings index, chemical & allied products (1992 = 100)	Apr. '24	=	225.0	Mar. '24	=	227.0	Feb. '24	=	226.0	Apr. '23	=	219.5
Productivity index, chemicals & allied products (1992 = 100)	May '24	=	92.2	Apr. '24	=	92.7	Mar. '24	=	93.1	May '23	=	93.1

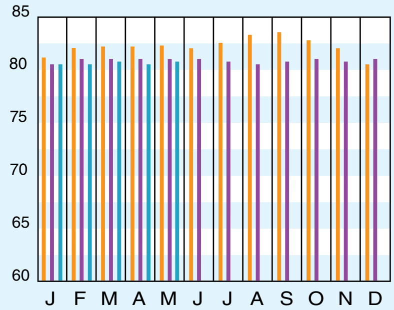
CPI OUTPUT INDEX (2017 = 100)†



CPI OUTPUT VALUE ($ BILLIONS)



CPI OPERATING RATE (%)



*Due to discontinuance, the Index of Industrial Activity has been replaced by the Industrial Production in Manufacturing index from the U.S. Federal Reserve Board.
†For the current month's CPI output index values, the base year was changed from 2012 to 2017
Current business indicators provided by S&P Global Market Intelligence, New York, N.Y.

CURRENT TRENDS

The preliminary value for the *CE* Plant Cost Index (CEPCI; top) for May 2024 (most recent available) rose slightly compared to the previous month's value. The final value for April 2024 was itself upwardly revised. The small uptick in the May CEPCI was a result of increases in the Equipment and Construction Labor subindices. The Buildings and Engineering & Supervision subindices saw very small declines. The current CEPCI value now sits at 1.1% lower than the corresponding value from May 2023. Meanwhile, the Current Business Indicators (middle) show increases in the CPI output index and the CPI operating rate for May 2024, and an increase in the CPI value of output for April 2024.